

2005

SOURCEBOOK FOR LAND USE, LAND-USE CHANGE AND FORESTRY PROJECTS

Timothy Pearson, Sarah
Walker and Sandra Brown

With input from Bernhard Schlamadinger
(Joanneum Research), Igino Emmer (Face
Foundation), Wolfram Kägi (BSS) and Ian
Noble, Benoit Bosquet and Lasse Ringius
(World Bank)



SOURCEBOOK FOR LAND USE, LAND-USE CHANGE AND FORESTRY PROJECTS

**Timothy Pearson, Sarah Walker
and Sandra Brown**

With input from Bernhard Schlamadinger,
Igino Emmer, Wolfram Kägi, Ian Noble,
Benoit Bosquet and Lasse Ringius

CONTENTS

1. PURPOSE AND SCOPE.....	1
2. INTRODUCTION TO THE KYOTO PROTOCOL AND THE CLEAN DEVELOPMENT MECHANISM PROJECT CYCLE	2
2.1. The Clean Development Mechanism	2
3. INTRODUCTION TO THE BIOCARBON FUND AND THE BIOCARBON FUND CYCLE	3
4. CONCEPTS OF ADDITIONALITY, BASELINE, LEAKAGE AND PERMANENCE	4
4.1. Additionality.....	4
4.2. Baseline	4
4.3. Leakage	5
4.4. Permanence	5
5. SPECIFIC CONSIDERATIONS FOR THE KYOTO PROTOCOL	6
5.1. Currently Acceptable LULUCF Projects.....	6
5.2. The Eligibility of Lands	6
5.2.1. 31 December 1989 Rule	6
5.2.2. Definitions of Forest	6
5.2.3. The Eligibility Tool	6
5.3. Additionality Tests.....	7
5.4. Choice of Baseline	8
5.5. Crediting.....	9
5.6. Submission of New Afforestation/Reforestation Methodology	10
6. DEVELOPING A MEASUREMENT PLAN	11
6.1. The Concepts of Accuracy, Precision and Being Conservative.....	11
6.2. Define the Project Boundaries.....	12
6.3. Stratify the Project Area.....	12
6.4. Decide Which Carbon Pools to Measure	12
6.5. Determine Type, Number and Location of Measurement Plots	13
6.5.1. Type of Plots.....	13
6.5.2. Number of Plots.....	15
6.5.3. Location of Plots	18
6.6. Determine Measurement Frequency	18
7. FIELD MEASUREMENTS.....	19
7.1. Preparation for Fieldwork	19
7.2. Trees, Palms and Lianas	20
7.2.1. Trees	20
7.2.2. Palms	21
7.2.3. Lianas	21
7.3. Non-Tree Vegetation.....	21

7.4. Dead Wood	22
7.4.1. Standing Dead Wood	22
7.4.2. Downed Dead Wood	22
7.5. Forest Floor (Litter Layer)	22
7.6. Soil	23
8. ANALYSIS	24
8.1. Live Tree Biomass	24
8.2. Belowground Tree Biomass	27
8.3. Non-Tree Vegetation	28
8.4. Standing Dead Wood	28
8.5. Downed Dead Wood	28
8.6. Forest Floor (Litter Layer)	29
8.7. Soil	29
8.9. Estimating Net Change	30
8.9.1 Uncertainty	30
9. NON-CO₂ GASES	33
9.1 Transport and Machinery	33
9.2. Fertilisation	33
9.3. Fire	33
10. QUALITY ASSURANCE AND QUALITY CONTROL	34
10.1. QA/QC for Field Measurements	34
10.2. QA/QC for Sample Preparation and Laboratory Measurements	34
10.3. QA/QC for Data Entry	34
10.4. QA/QC for Data Archiving	35
11. GUIDANCE ON LEAKAGE	36
12. REFERENCES	38
APPENDIX A: GLOSSARY	39
APPENDIX B: CREATING BIOMASS REGRESSION EQUATIONS	40
Method 1: Developing Biomass Equations	40
Method II: Mean Tree Biomass Estimate	40
APPENDIX C: PUBLISHED BIOMASS REGRESSION EQUATIONS	41
Temperate Equations:	41
Tropical Equations:	43
Agroforestry Equations	44
APPENDIX D: CHECKLIST FOR CDM AFFORESTATION/REFORESTATION PROJECTS	46

1. PURPOSE AND SCOPE

This sourcebook is designed to be a guide for developing and implementing land use, land-use change and forestry (LULUCF) projects for the BioCarbon Fund of the World Bank that meet the requirements for the Clean Development Mechanism (CDM) of the Kyoto Protocol. Only project types and carbon pools that are eligible for credit under the CDM during the first commitment period (2008-2012) are covered.

With its user-friendly format, the sourcebook introduces readers to the CDM processes and requirements, and provides methods and procedures to produce accurate and precise estimates of changes in carbon stocks. The sourcebook is not designed as a primer on field measurement techniques, although guidance is given.

The sourcebook is intended as an addition to the *IPCC Good Practice Guidance on Land Use, Land-Use Change and Forestry* (2003), providing additional explanation, clarification and enhanced methodologies. It is designed to be used alongside the Good Practice Guidance.

ACKNOWLEDGEMENTS

Ken MacDicken, David Shoch and Matt Delaney played a central role in developing the methods presented here. We also wish to thank the organisations and agencies that have funded our work over the past 10 years, which made possible the advances we have achieved – in particular, The Nature Conservancy, US Agency for International Development, USDA Forest Service, United Nations Development Programme and World Bank. Finally, we would like to acknowledge Ian Monroe for creating the illustration on page 21.

Content on new methodologies and reasons for failure in the first year of consideration were largely derived from comments by Martin Enderlin (chair of the A/R Working Group and member of Clean Development Mechanism Executive Board) during his presentation at the Winrock International side event at COP/MOP 1 in Montreal in 2005. The title of the side event was “Gaining approval for Land Use, Land-Use Change and Forestry projects and project methodologies under the Clean Development Mechanism: lessons learned”.

2. INTRODUCTION TO THE KYOTO PROTOCOL AND THE CLEAN DEVELOPMENT MECHANISM PROJECT CYCLE

Carbon exists in everything that is living or has ever lived. There is a perpetual cycle of carbon being sequestered on earth and emitted back into the atmosphere. Humankind increasingly influences this carbon cycle through the burning of ever-greater quantities of oil, gasoline and coal and the cutting down of forests. It is argued that the human-induced accumulation of carbon dioxide (CO₂) and other greenhouse gases in the atmosphere is driving climate change. It is likely that current atmospheric concentrations are at a 20-million-year high and that current rates of accumulation are unprecedented [1].

The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) was developed as an attempt to confront and begin to reverse the rising CO₂ concentrations. In 1997, 38 industrialised nations signed the Kyoto Protocol and agreed to cut their emissions of greenhouse gases between 2008 and 2012 to levels 5.2 per cent below 1990 levels. By June 2005, 150 countries had ratified the Kyoto Protocol, including 34 of the 38 industrialised nations whose emissions account for 61.6 per cent of all industrialized nations' emissions.

Emissions of CO₂ from land use and land-use change represent up to 20 per cent of current CO₂ emissions from burning fossil fuels [2, 3]. Changes in land-use can positively impact atmospheric CO₂ concentrations by either: i) decreasing emissions that would occur without intervention, or ii) sequestering CO₂ from the atmosphere into vegetation and the associated soil. Preventing deforestation, decreasing the impact of logging or preventing the drainage of wetlands or peat lands are practices that decrease emissions. In contrast, planting trees, changing agricultural tillage or cropping practices, or re-establishing grasslands sequester carbon.

The Kyoto Protocol recognised the role that changes in the use of land and forests have on the global carbon cycle. Parties to the Protocol can use credits generated either by sequestering carbon or by reducing carbon emissions from land use to help them reach their reduction targets. Carbon credits can be produced within the emission-source country or in an alternative industrialised nation (Joint Implementation [JI], Article 6). In addition, the Protocol includes a mechanism by which industrialised (Annex I) nations can offset some of their emissions by investing in projects in non-industrialised (non-Annex I) nations (CDM, Article 12).

2.1. The Clean Development Mechanism

"The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the convention, and to assist parties included in Annex I in achieving compliance with their quantified limitation and reduction commitments."

Article 12 of the Kyoto Protocol (1997)

The UNFCCC established a CDM Executive Board that is charged with approving or rejecting project designs and methodologies, registering and administering project auditors (designated operational entities) and approving the issuance of certified emission reductions.

For each project, a Project Design Document must be submitted that employs an approved methodology, including baseline and monitoring methods. It is envisaged that, in the future, a group of approved methodologies will exist that can be applied to new projects. However at the time of writing, only one methodology had been accepted. The Project Design Document describes the project, illustrates how the methodology will be applied, estimates the greenhouse gases and environmental and socio-economic impacts of the project, including all baseline information, and presents a monitoring plan.

For the first commitment period (2008-2012), Annex I Parties are limited in the extent to which they can use offsets from LULUCF to meet their reduction commitments. The total additions to an Annex I Party's assigned amount from emissions that can result from LULUCF project activities under the CDM is constrained at one per cent of base year emissions of that country per year for the five years of the commitment period.

3. INTRODUCTION TO THE BIOCARBON FUND AND THE BIOCARBON FUND CYCLE

The World Bank's BioCarbon Fund provides carbon finances for projects that sequester or conserve greenhouse gases in forest, agro- and other ecosystems. The BioCarbon Fund aims to "test and demonstrate how land use, land-use change and forestry activities can generate high-quality emission reductions with environmental and livelihood benefits that can be measured, monitored and certified and stand the test of time".

BioCarbon Fund projects have to fulfill criteria to ensure the fund meets its own targets in the areas of Climate and Environment; Poverty Alleviation; Project Management and Learning; and Portfolio Balance.

Each BioCarbon Fund project is expected to deliver between 400,000 and 800,000 tons of CO₂ equivalent (CO₂e) over a period of 10 to 15 years. In return, a typical project will receive about US\$2-3 million in payments (\$3-4 per tonne CO₂e).

Prospective project developers submit a Project Idea Note. If both parties agree to take the proposal further, more formal documents are prepared, including an Emissions Reductions Purchase Agreement and a Project Design Document that is submitted to the CDM Executive Board.

As of spring 2005, 140 Project Idea Notes had been submitted to the BioCarbon Fund and the window of opportunities for submission closed. However, future windows of opportunities for submissions are envisaged.

For information, go to carbonfinance.org/biocarbon/home.cfm.

4. CONCEPTS OF ADDITIONALITY, BASELINE, LEAKAGE AND PERMANENCE

This section introduces four core and interlinked concepts that need to be understood to develop projects and acceptable methodologies to deliver credits under the CDM of the Kyoto Protocol. They are: **additionality, baseline, leakage and permanence**. Subsequent sections of this sourcebook will draw upon these concepts in the context of the issues of developing methodologies.

4.1. Additionality

The CDM is a carbon-neutral process. It allows an Annex I Party and a non-Annex I Party to co-operate and carry out a project in the non-Annex I Party that will sequester carbon (or reduce emissions). Certified emission reduction credits (CERs) are created through the project and transferred to the Annex I Party, which is now able to emit an equivalent number of units of carbon while meeting its targets. Thus, the atmospheric concentration of greenhouse gases remains unchanged as a result of the transaction. The Annex I Party is assisted in meeting its commitments cost-effectively while, in well-designed projects, the non-Annex I Party benefits in meeting sustainable development goals.

However, if the project that sequesters the carbon (or reduces emissions) would have taken place without the CDM transaction, then greenhouse gases in the atmosphere will increase as a result of the transfer of CERs. For example, if an area would have been reforested, either through deliberate management action or through natural processes, irrespective of the CDM transaction, then the CDM transaction simply allows the Annex I Party to emit more greenhouse gases and the atmosphere is worse off than it would have been without the transaction.

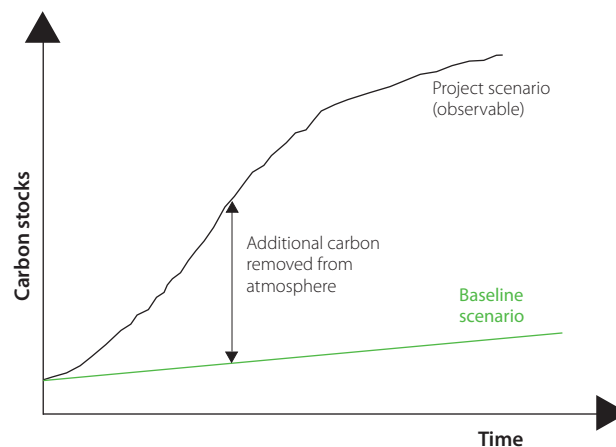
This is the purpose of the additionality clause in Article 12 of the Kyoto Protocol. Some confusion has arisen, however, because the agreed definition of additionality does not fully capture these core concepts. The definition agreed at Ninth Conference of the Parties (COP9) in Milan in 2003 is: “The proposed afforestation or reforestation project activity under the CDM is additional if the actual net greenhouse gas removals by sinks is increased above the sum of the changes in carbon stocks in the carbon pools within the project boundary that would have occurred in the absence of the registered CDM afforestation or reforestation project activity...”. This definition focuses more on identifying the additional component than on project eligibility. Further guidance from the CDM Executive Board and recommended steps for dealing with additionality and baselines are outlined in Sections 5.3 and 5.4. However the essential question that must be asked of each project is: *How much carbon is being sequestered as a direct result of the CDM transaction?* If more CERs are issued than this amount, then the project increases greenhouse gases in the atmosphere. This test applies equally to LULUCF and non-LULUCF projects.

4.2. Baseline

As stated above, CDM afforestation and reforestation projects enhance greenhouse gas removals in one country to permit an equivalent quantity of greenhouse gas emissions in another country, without changing the global emission balance. Technically, the CDM is a baseline-and-credit trade mechanism, not a cap-and-trade mechanism. Therefore, enhancements of removals by afforestation and reforestation projects must create real, measureable and long-term benefits related to the mitigation of climate change (Kyoto Protocol, Article 12.5b), and must be *additional* to any that would occur *in the absence* of the certified project activity (Kyoto Protocol, Article 12.5c). The “in the absence” scenario is also referred to as the **baseline scenario**.

The Marrakech Accords define a baseline scenario as one that “reasonably represents greenhouse gas emissions that would occur in the absence of the proposed project activity” and is derived using an approved baseline method. The Marrakech Accords also state that the project baseline shall be established “in a transparent and conservative manner regarding the choices of approaches, assumptions” and that it shall be established “on a project-specific basis”. In summary, the baseline is the most likely course of action and development over time, in the absence of CDM financing.

The figure below shows the time-path of carbon stocks in the project and baseline scenarios.



The baseline scenario can either be estimated and validated upfront and then “frozen” for the first phase of the crediting period (that is, 30 years or the first 20 years of up to 60 years), or it is also possible to monitor the baseline during the afforestation or reforestation project. However, even in the latter case, it is still necessary to establish a methodology upfront on how to select the con-

trol plots and monitor them, and to provide an upfront estimation of the baseline, including the associated emissions and removals of greenhouse gases (the upfront estimation is for information only – the results of the monitored baseline would be used for calculating emission reductions). The advantage of an upfront estimated and “frozen” baseline is that there is greater certainty about the emission reductions generated by the project. This is the option that has been used by most projects to date.

4.3. Leakage

Some projects will be successful in sequestering more carbon within the project area, but the project activities may change activities or behaviours elsewhere. These changes may lead to reduced sequestration or increased emissions outside the project boundary, negating some of the benefits of the project. This is called leakage. A simple example is a project that reforests an area of poor quality grazing land, but leads to the owners of the displaced livestock to clear land outside the project boundaries to establish new pastures. The types of activities that might result in leakage vary with the type of projects, but both LULUCF and non-LULUCF projects are subject to leakage. Leakage can often be minimised by good project design – such as in the example above by including improved pasture management around the plantation so that displaced livestock can be accommodated without further clearing. Section 11 deals with leakage in more detail.

4.4. Permanence

During the negotiations leading up to the Kyoto Protocol and subsequently, there was considerable concern that credits issued for carbon sequestration would be subject to a risk of re-emission, due to either human action or natural events such as wildfires. This was called the permanence risk and it is unique to LULUCF projects under the Protocol. Eventually, Parties agreed that credits arising from CDM afforestation and reforestation projects should be temporary, but could be re-issued or renewed every five years after an independent verification to confirm sufficient carbon was still sequestered within the project to account for all credits issued.

This deals effectively with the permanence risk and guarantees that any losses of sequestered carbon for which credits have been issued will have to be made up through either additional sequestration elsewhere or through credits derived from non-LULUCF activities. Two types of temporary credits were agreed: temporary CERs and long-term CERs. Some accounting issues relating to these credits are described in Section 5.5. There are additional issues in relation to pricing, restrictions on replacement, etc, that also need to be taken into account. The BioCarbon Fund has documentation to guide project managers on these issues.

5. SPECIFIC CONSIDERATIONS FOR THE KYOTO PROTOCOL

5.1. Currently Acceptable LULUCF Projects

During the first commitment period (2008-2012), the only LULUCF project types that are eligible for the CDM are afforestation and reforestation.

Afforestation is the direct human-induced conversion of land that has not been forested for a period of at least 50 years, to forested land through planting, seeding and/or the human-induced promotion of natural seed sources.

Reforestation is the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or human-induced promotion of natural seed sources, on land that was forested but has been converted to non-forest land. For the first commitment period, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December, 1989.

In practice, no distinction is made under the CDM between afforestation and reforestation.

Neither forest management nor forest protection/conservation are currently eligible. The project types eligible in the second commitment period have not yet been established.

5.2. The Eligibility of Lands

5.2.1. 31 December 1989 Rule

The criterion that all projects must meet is for no forest to be present within the project boundaries between 31 December 1989 and the start of the project activity. Proof of forest absence could take the form of aerial photographs or satellite imagery from 1989 or before, or official government documentation confirming the lack of forests. Where proof of these types does not exist, multiple independent, officially witnessed statements by local community members should suffice.

5.2.2. Definitions of Forest

The decision of what constitutes a forest has implications for what lands are available for afforestation and reforestation activities. National presiding authorities in non-Annex I countries, known as Designated National Authorities, have the role of deciding for their country where to lay the thresholds from a range determined at COP9, namely:

- Minimum tree crown cover value between 10 and 30 per cent;
- Minimum land area value between 0.05 and 1 hectare;
- Minimum tree height value between 2 and 5 metres.

5.2.2.1. Implications

There are various implications for project eligibility based on which forest definitions are chosen.

Tree crown cover

A low tree crown cover threshold when defining a forest permits the inclusion of restoration of open woodland type forest as a potential afforestation/reforestation project. Agroforests are also likely to fit under this low threshold, as such systems often do not attain high crown cover.

A high tree crown cover threshold would allow for the inclusion of many degraded forests as the starting condition for a potential afforestation/reforestation project. However, such a threshold would likely eliminate the use of agroforestry practices unless a high density of trees was used.

Land area

A low minimum land area threshold permits the inclusion of small patches of forests around farms and houses that may also serve as woodlots.

A high minimum land area threshold will encourage large contiguous areas of forest with the consequent cobenefits to biodiversity, land stabilisation and water quality.

Tree height

A low tree height threshold permits the inclusion of short, woody forest vegetation, such as those that grow on poor soils or at altitude. It would also allow for the inclusion of commercial woody species such as coffee and some spice trees.

A high tree height value permits the inclusion of some degraded forests as the starting condition for a potential afforestation/reforestation project. Tree height is based on potential, not current height, so a low definition would allow the inclusion of shrubs but not immature trees.

Ideally, the Designated National Authority would consider the ecosystems in the country and which forest definitions would best serve national development goals. This will be simpler for a country that is relatively homogenous environmentally than a highly diverse nation with varied topography, soils and climates.

5.2.3. The Eligibility Tool

The CDM Executive Board has developed a mandatory tool to be

used to demonstrate the eligibility of lands (Executive Board 22nd Meeting, Annex 16). Following this decision, eligibility criteria are no longer required in methodology documents but the eligibility tool should be applied for the Project Design Document.

Procedures to define the eligibility of lands for afforestation and reforestation project activities

1. Project participants shall provide evidence that the land within the planned project boundary is eligible as an afforestation/reforestation CDM project activity following the steps outlined below.
 - (a) Demonstrate that the land at the moment the project starts is not a forest by providing information that:
 - i. The land is below the forest national thresholds (crown cover, tree height and minimum land area) for forest definition under Decisions 11/CP.7 and 19/CP.9, as communicated by the respective Designated National Authority; and
 - ii. The land is not temporarily unstocked as a result of human intervention such as harvesting or natural causes or is not covered by young natural stands or plantations which have yet to reach a crown density or tree height in accordance with national thresholds and which have the potential to revert to forest without human intervention.
 - (b) Demonstrate that the activity is a reforestation or afforestation project activity:
 - i. For reforestation project activities, demonstrate that on 31 December 1989, the land was below the forest national thresholds (crown cover, tree height and minimum land area) for forest definition under Decision 11/CP.7, as communicated by the respective Designated National Authority.
 - ii. For afforestation project activities, demonstrate that the land is below the forest national thresholds (crown cover, tree height and minimum land area) for forest definition under Decision 11/CP.7, as communicated by the respective Designated National Authority, for a period of at least 50 years.
2. In order to demonstrate steps 1(a) and 1(b), project participants shall provide one of the following verifiable items of information:
 - (a) Aerial photographs or satellite imagery, complemented by ground reference data; or
 - (b) Ground-based surveys (land-use permits, land-use plans or information from local registers such as cadastre, owners register, land use or land management register); or
- (c) If options (a) and (b) are not available/applicable, project participants shall submit a written testimony which was produced by following a participatory rural appraisal methodology.

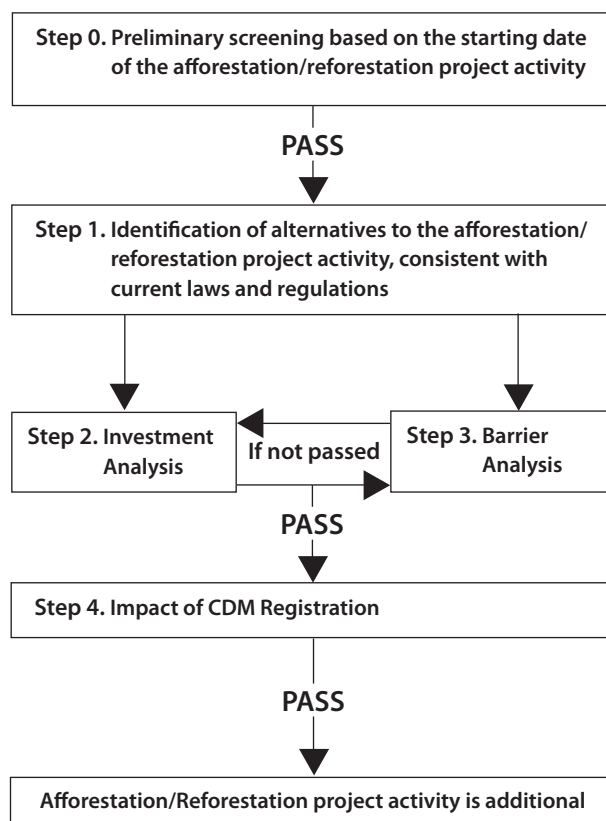
Participatory rural appraisal is an approach to the analysis of local problems and the formulation of tentative solutions with local stakeholders. It makes use of a wide range of visualisation methods for group-based analysis to deal with spatial and temporal aspects of social and environmental problems.

From Executive Board 22nd Meeting, Annex 16

5.3. Additionality Tests

The CDM Executive Board also developed a step-wise tool to test the additionality of prospective project activities (Executive Board 16th Meeting). A refined tool, especially for afforestation/reforestation, was approved at the Executive Board 21st Meeting. Project developers are encouraged to use the tool to show the project activity would not have occurred in the absence of carbon financing.

From Executive Board 21st Meeting, Annex 16



Step 0 – Preliminary screening based on starting date of afforestation/reforestation project activity

Registration of CDM project activities is only now beginning to occur, but the CDM Executive Board does not want to penalise project activities that were mobilised early. Project participants must provide evidence that the start date of the activity was after 31 December 1999 and that the incentive from the sale of greenhouse gas allowances was seriously considered in the decision to proceed with the activity.

Step 1 – Identification of alternatives to the afforestation/reforestation project activity, consistent with current laws and regulations

Realistic and credible alternative land uses must be identified, including continuation of the current situation. The applicable legal and regulatory requirements must be discussed for all alternatives. If the proposed project activity is the only alternative that is legally required, and the requirements are enforced, then the project is not additional.

Project developer may choose Step 2 or 3 or both.

Step 2 – Investment analysis

Is the proposed project activity economically or financially less attractive than the other alternatives (identified in Step 1) without the revenue from the sale of carbon credits?

Step 3 – Barrier analysis

Does the proposed project activity face barriers to prevent implementation? Does this barrier fail to prevent the implementation of at least one of the alternatives (identified in Step 1)?

These may include include:

- Investment barriers – for example, no source of funding to overcome initial costs of establishing the activity;
- Technological barriers – for example, lack of properly skilled or trained labour, or lack of infrastructure to implement project;
- Prevailing practice barriers – for example, the project activity is a new practice in the country or region.

Step 4 – Impact of CDM registration

An explanation is required of how the benefits and incentives of CDM registration will alleviate economic

and financial hurdles (Step 2) and/or other barriers (Step 3), enabling the project activity to be undertaken.

If there is an economic or financial incentive to undertake the project without the CDM, and there are no barriers to the project activity, then the project activity is not additional.

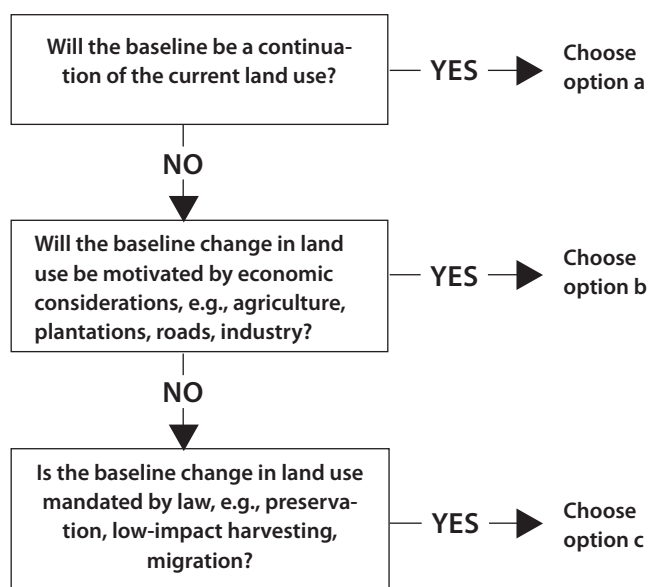
More detail on the Additionality Tool can be found in Annex 1 of the report on the 16th Meeting of the CDM Executive Board (<http://cdm.unfccc.int/EB/Meetings/021/eb21repan16.pdf>).

5.4. Choice of Baseline

Three approaches to creating a baseline were proposed at COP9:

- Existing or historical, as applicable, changes in carbon stocks in the carbon pools within the project boundary;
- Changes in carbon stocks in the carbon pools within the project boundary from a land use that represents an economically attractive course of action, taking into account barriers to investment;
- Changes in carbon stocks in the carbon pools within the project boundary from the most likely land use at the time the project starts.

Project developers have to select the most appropriate approach and to justify their selection.



Option a) indicates a continuation of the current land use, b) indicates a change in land use motivated by economic considerations (for example, development or plantations or agroforestry), and c) indicates a change that is not motivated by economic considerations (for example, changing legal requirements).

For afforestation/reforestation projects, project practitioners should choose option a) if the baseline is a continuation of the current land-use practice. If a change in the law or in enforcement of the law would lead to a change in land use, select option c). Any other change in land use will be economically motivated and option b) should be chosen.

5.5. Crediting

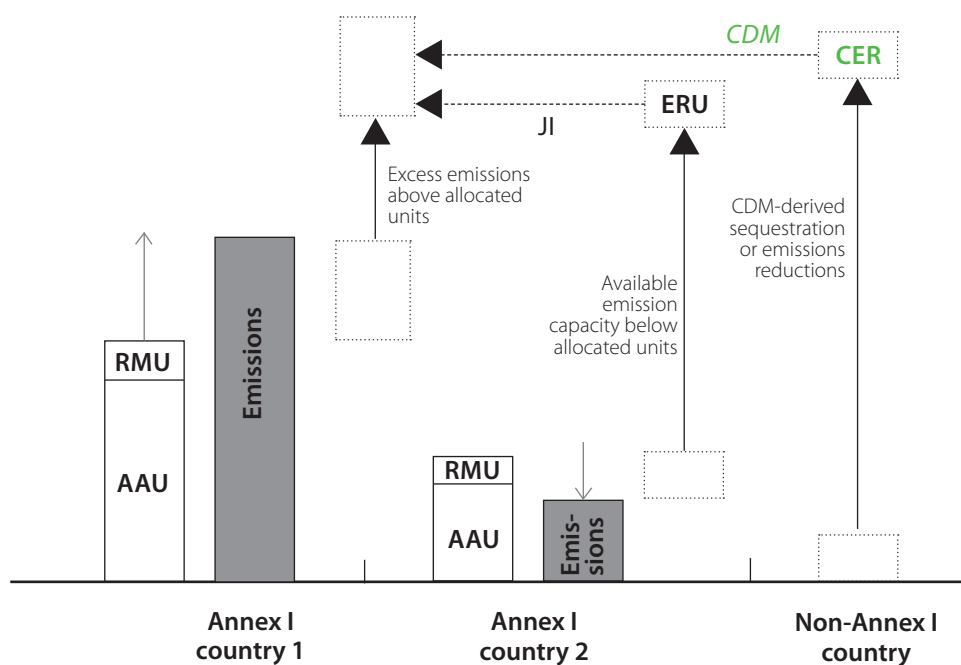
Central to the Kyoto Protocol process are the allocation units and crediting units. All units are in metric tonnes of CO₂e – that is, when greenhouse gases other than CO₂ are converted into an equivalent quantity of CO₂ in terms of global warming potential. (One tonne of nitrogen dioxide [N₂O] is equal to 296 tonnes of CO₂e and 1 tonne of methane [CH₄] is equal to 21 tonnes of CO₂e).

Each Annex I country has Assigned Amount Units (AAUs) which total to the reduction target for that country for the end of the crediting period. Any carbon sequestration an Annex I country achieves is added to their AAU total. Sequestration is measured in Removal Units (RMUs).

If a country fails to reach its target with domestic AAUs and RMUs it can turn to flexible mechanisms: JI for trading between Annex I countries and the CDM for credits derived in non-Annex I countries. Emission Reduction Units (ERUs) are the units for JI trading and Certified Emission Reduction units (CERs) are the units for CDM trading. An Annex I country that more than meets its target can convert its remaining AAUs and RMUs into ERUs to trade with Annex I countries that have not achieved the required reductions.

In the Figure below, the first Annex I country's emissions exceed its total allowable AAUs and RMUs. In contrast, the second Annex I country has low emissions and a surplus of AAUs and RMUs that it can convert to ERUs and sell under the JI programme. The first country is able to overcome its excessive emissions by purchasing ERUs from the second Annex I country in addition to CERs generated from a project in a non-Annex I country under the CDM.

For LULUCF projects under the CDM, the fear of lack of permanence (Section 4.4) has led to the creation of expiring CER units. Two similar forms of certified emissions reduction schemes are offered – the temporary CER (tCER) and the long-term CER (lCER). For both types, there is a choice between a single crediting period (maximum 30 years) or a period of 20 years with the possibility of two renewals (totalling 60 years). Once a CER cred-



iting period is over, the Annex I country must replace the carbon either by purchasing another CER or by replacing it with an RMU or ERU.

The tCERs last for just five years, at which time they can be reissued (if verification has occurred) or the Annex I country must replace them. When a project developer retires a tCER after a crediting period is over (after which, CDM regulations on that tCER will cease), the developer is then free to harvest the trees if desired. The fees for issuing tCERs will likely be charged every five years which could significantly raise the cost of this option. At the end of the crediting period, all tCERs expire.

In contrast, ICERs last for the entire length of the crediting period, but must be replaced either as soon as verification shows the carbon stock has decreased or if no verification has occurred for a period of five years. For a low-risk ICER, the price will approach that of an energy CER credit [4]. At the end of the crediting period, all ICERs also expire.

The ICERs are more desirable for the project developer in that they will possess a higher value. Yet a purchaser will not invest in ICERs for a project in which there is significant risk – in this situation, the five-year obligation of tCERs is preferable. Additionally, if the price of CERs is expected to increase over time, a project developer may want to sell tCERs in the hope of receiving greater payment for future tCERs.

5.6. Submission of a New Afforestation/Reforestation Methodology

All projects submitted to the CDM Executive Board must include a Project Design Document in which an approved afforestation/reforestation methodology is applied. If the proposed project does not meet the conditions of any of the approved methodologies, a new afforestation/reforestation methodology must be submitted for approval along with the Project Design Document, illustrating how the new methodology can be applied. New methodologies are reviewed by the Afforestation/Reforestation Working Group and expert reviewers before being finally approved by the CDM Executive Board.

All new methodologies should be user-oriented, concise and provide step-by-step tools. The methodology must address all applicable issues, modalities, decisions by the COP and rules of the Executive Board. The conditions for the new methodology applicability and assumptions must be clear, and explain why a new methodology is warranted.

The submission of new methodologies has been a learning process for all involved. During the first year, the primary issues that caused new methodologies to be rejected included improper or lacking explanation regarding:

- additionality;
- methods for determining the project boundary;
- description of the baseline approach, justification for this approach and land-use scenario determination;
- consideration and selection of carbon and non-CO₂ greenhouse gas pools;
- methods for determining net anthropogenic greenhouse gas removals by sinks; as well as
- inadequacy in making recommended changes if the new methodology was being submitted for a second time.

Secondary issues that also caused new methodologies to fail included improper or lacking explanation regarding:

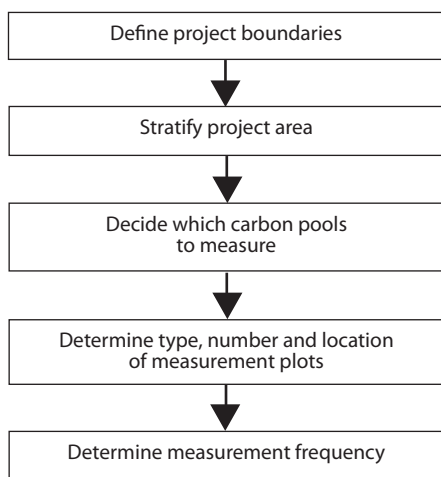
- methods for creating a baseline of net greenhouse gas removals by sinks;
- methods for estimating actual net greenhouse gas removals by sinks;
- systems for addressing leakage;
- methods for compiling project emissions;
- improper or inadequate description of models, formulas, algorithms and data sources used;
- methods for addressing uncertainties; as well as
- the overall quality, drafting and language.

Care should be taken to adequately address all of the above concerns. Due to the evolving nature of the negotiations, the CDM website (www.unfccc.int/CDM) should be regularly consulted.

6. DEVELOPING A MEASUREMENT PLAN

The guidance given here is intended as additional to the IPCC *Good Practice Guidance on Land Use, Land-Use Change and Forestry* (2003), providing elaboration, clarification and enhanced methodologies. The sourcebook should be used alongside the Good Practice Guidance. It is also worth noting that the science of forestry has been in development for hundreds of years. Many textbooks exist that provide more detail than is possible to include in this sourcebook – a good example is *Forest Measurements* [5].

The steps to preparing a robust measuring plan can be summarised in the following flow chart:



6.1. The Concepts of Accuracy, Precision and Being Conservative

To estimate the carbon stock on the land, one could measure everything – every single tree for example in the tens, hundreds or thousands of hectares of the project area. Complete enumerations are almost never possible, however, in terms of time or cost. Consequently we must sample.

Sampling is the process by which a subset is studied in order to allow generalisations to be made about the whole population or area of interest. The values attained from measuring a sample are an estimation of the equivalent value for the entire area or population. We need to have some idea of how close the estimation is to reality and this is provided by statistics.

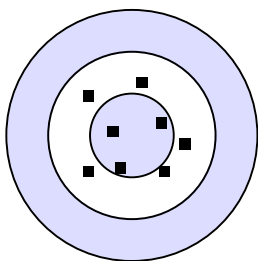
There are two important statistical concepts that have to be understood: **accuracy** and **precision**.

Accuracy is how close your sample measurements are to the actual value. Accuracy details the agreement between the true value and repeated measured observations or estimations of a quantity.

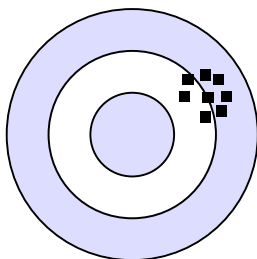
Precision is how well a value is defined. In sampling, precision illustrates the level of agreement among repeated measurements of the same quantity. This is represented by how closely grouped are the results from the various sampling points or plots.

A popular analogy is a bull's eye on a target. In this analogy, how tightly the arrows are grouped is the precision, while how close they are to the centre is the accuracy. Below in (A), the points are close to the centre and therefore accurate, but they are widely spaced and therefore imprecise. In (B), the points are closely grouped and therefore precise, but are far from the centre and so inaccurate. In (C), the points are close to the centre and tightly grouped – therefore both accurate and precise.

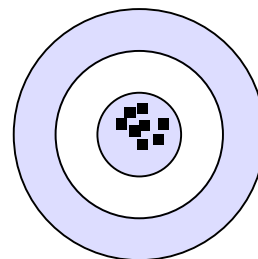
(A) Accurate, but not precise



(B) Precise, but not accurate



(C) Accurate and precise



When sampling for carbon, we want measurements that are both accurate (that is, close to the reality for the entire population) and precise (that is, closely grouped) so we can have confidence in the result.

Sampling a subset of the land for carbon estimation involves taking measurements in a number of locations or “plots”. The number of plots is predetermined to ensure precision. The average value when all the plots are combined represents the wider population and we can tell how representative it is by looking at the confidence interval. A 95 per cent confidence interval is a common and appropriate measure which tells us that, 95 times out of 100, the true carbon density lies within the interval. If the interval is small, then the result is precise.

A third concept that is followed in carbon measurement work is that of being **conservative**. Sometimes it is just not possible to measure a particular pool, or a very broad estimate has to be made. In these cases, the most appropriate action is to pursue the most conservative options within the possible biological range.

For example, if only an imprecise measurement were possible for a project activity, then the most conservative approach would be to report the lower bound of the 95 per cent confidence interval. In contrast, to be conservative on the baseline, the higher bound of the confidence interval would be used. As a result, a lower sequestration total would be reported than if the mean had been used, but the total will be appropriately conservative.

6.2. Define the Project Boundaries

Project activities can vary in size from tens of hectares to hundreds of thousands of hectares, and can be confined to a single or several geographic areas. The project area may be one contiguous block of land under a single owner, or many small blocks of land spread over a wide area with a large number of small landowners or a few large ones. The spatial boundaries of the land need to be clearly defined and properly documented from the start to aid accurate measuring, accounting and verification.

STEP 1 – Obtain a map of your project area.

STEP 2 – Define the boundaries using features on the map or co-ordinates attained with a global positioning system.

6.3. Stratify the Project Area

To facilitate fieldwork and increase the accuracy and precision of measuring and estimating carbon, it is useful to divide the project area into sub-populations or “strata” that form relatively homogeneous units. In general, stratification also decreases the costs of monitoring because it typically diminishes the sampling efforts necessary, while maintaining the same level of confidence (it does so because there is a smaller variation in carbon stocks in each stratum than in the whole area). Useful tools for defining strata include ground-truthed maps from satellite imagery, aerial photographs and maps of vegetation, soils or topography.

The size and spatial distribution of the land area does not influence site stratification – whether one large contiguous block of land or many small parcels are considered the population of interest, they can be stratified in the same manner. The stratification should be carried out using criteria that are directly related to the variables to be measured and monitored – for example, the carbon pools in trees. Note there is a trade-off between the number of strata and sampling intensity. The purpose of stratification should be to partition natural variation in the system and so reduce monitoring costs. If stratification leads to no, or minimal, change in costs, then it should not be undertaken.

Potential stratification options include:

- Land use (for example, forest, plantation, agroforestry, grassland, cropland, irrigated cropland);
- Vegetation species (if several);
- Slope (for example, steep, flat);
- Drainage (for example, flooded, dry);
- Age of vegetation;
- Proximity to settlement.

Typically, a project might have between one and six strata.

6.4. Decide Which Carbon Pools to Measure

There are six carbon pools applicable to afforestation/reforestation LU-LUCF project activities – aboveground trees, aboveground non-tree, belowground roots, forest floor (or litter), dead wood and soil organic matter. However, not all six pools will be significantly impacted in a given project.

At COP9, it was determined that “project participants may choose not to account for one or more carbon pools ... subject to the provision of transparent and verifiable information that the choice will not increase the expected net anthropogenic greenhouse gas removals by sinks”.

Therefore, a pool can be excluded as long as it can be reasonably shown that the pool will not decrease as part of the project ac-

tivity or will not increase as part of the baseline.

Beyond this stipulation, the selection of which pools to measure depends on several factors, including expected rate of change, magnitude and direction of change, availability and accuracy of methods to quantify change and the cost to measure. All pools that are expected to decrease as a result of activities should be measured and monitored. Pools that are expected to increase by only a small amount relative to the overall rate of change need not be measured or monitored.

Clearly it makes sense to measure and estimate the carbon pool in live trees and their roots for all project activities – trees are simple to measure and contain substantial amounts of carbon.

Aboveground non-tree or understory may need measuring if this is a significant component, such as where trees are only present at low densities (for example, savanna). But non-tree vegetation is generally not a significant biomass component in mature forest.

Forest floor and dead wood also tend to only be a significant component in mature forests. Dead wood is composed of standing dead trees and downed dead wood, and it is unlikely that significant quantities will accumulate in the 30 to 60 years of an afforestation/reforestation project.

Soil organic carbon is likely to change at a slow rate and is also likely to be an expensive pool to measure. However it should at least be considered, as sequestration of carbon into the soil, or prevention of emissions of carbon from soils, can be important – especially in grazing land and cropland systems – and omission of soil carbon is an omission of a source of reductions in atmospheric greenhouse gases. Potentially, where forest is planted on land that was previously grassland, a loss in soil carbon can occur (because of the very high soil carbon stocks in perennial grasslands).

As afforestation/reforestation projects have a maximum timeframe of 60 years, it may make sense economically and in terms of efficiency to only measure live biomass in trees, given that this pool will dominate the total biomass.

6.5. Determine Type, Number and Location of Measurement Plots

6.5.1. Type of Plots

6.5.1.1 Tree carbon pools

When estimating carbon changes in trees, permanent or temporary sampling plots could be used for sampling through time. *We recommend permanent plots for trees* as we see more advantages and fewer disadvantages. Permanent sampling plots are regarded

as statistically more efficient in estimating changes in forest carbon stocks than temporary plots, because there is high covariance between observations at successive sampling events [5].

Moreover, permanent plots permit efficient verification, if needed, at relatively low cost: a verifying organisation can find and measure permanent plots at random to verify, in quantitative terms, the design and implementation of the carbon monitoring plan. The disadvantage of permanent plots is that their location could be known and they could be treated differently than the rest of the project area – it is the responsibility of the auditing Designated Operational Entity to ensure that this has not occurred.

If permanent sample plots are used, marking or mapping the trees to measure the growth of individuals at each time interval is critical so that growth of survivors, mortality and ingrowth of new trees can be tracked. Changes in carbon stocks for each tree are estimated and summed per plot. Statistical analyses can then be performed on net carbon accumulation per plot, including ingrowth and losses due to mortality.

Where measurements are only made at one point in time – such as for baseline estimations – there is no value in marking plots and trees.

Shape and size of plots

The size and shape of the sample plots is a trade-off between accuracy, precision, time and cost for measurement. There are two types of plots – **single** plots of a fixed size or **nested** plots containing smaller sub-units of various shapes and sizes. Experience has shown that nested plots can be the most cost-efficient.

Nested plots are a practical design for sampling for recording discrete size classes of stems. They are well-suited to stands with a wide range of tree diameters or to stands with changing diameters and stem densities. Single plots may be preferred for systems with low variability, such as single species plantations.

Nested plots are composed of several full plots (typically two to four, depending upon forest structure), each of which should be viewed as separate. The plots can take the form of nested circles or rectangles. Circles work well if you have access to distance measuring equipment ([DME], for example, from Haglöf, Sweden) because then the actual boundary around the plot need not be marked. If DME is not available, it may be more efficient to use rectangular plots that are laid out with tape measures and stakes.

When trees attain the minimum size (measured by diameter at breast height, or dbh) for a nested plot, they are measured and included. When they exceed the maximum dbh size, measure-

ment of the tree in that nest stops and begins in the next larger nest. How to track and analyse data from nested plots is described, with examples, in Section 8.1.

It is possible to calculate the appropriate plot size specifically for each project; however, this adds an additional complication and an additional effort to the process. For simplicity, plot-size rules are presented in the table below that can be applied to any project. Experience has shown these plot sizes will represent a reasonable balance of effort and precision.

Stem Diameter	Circular Plot	Square Plot
[†] < 5cm dbh	1m	2m x 2m
5–20cm dbh	4m	7m x 7m
20–50cm dbh	14m	25m x 25m
> 50cm dbh	20m	35m x 35m

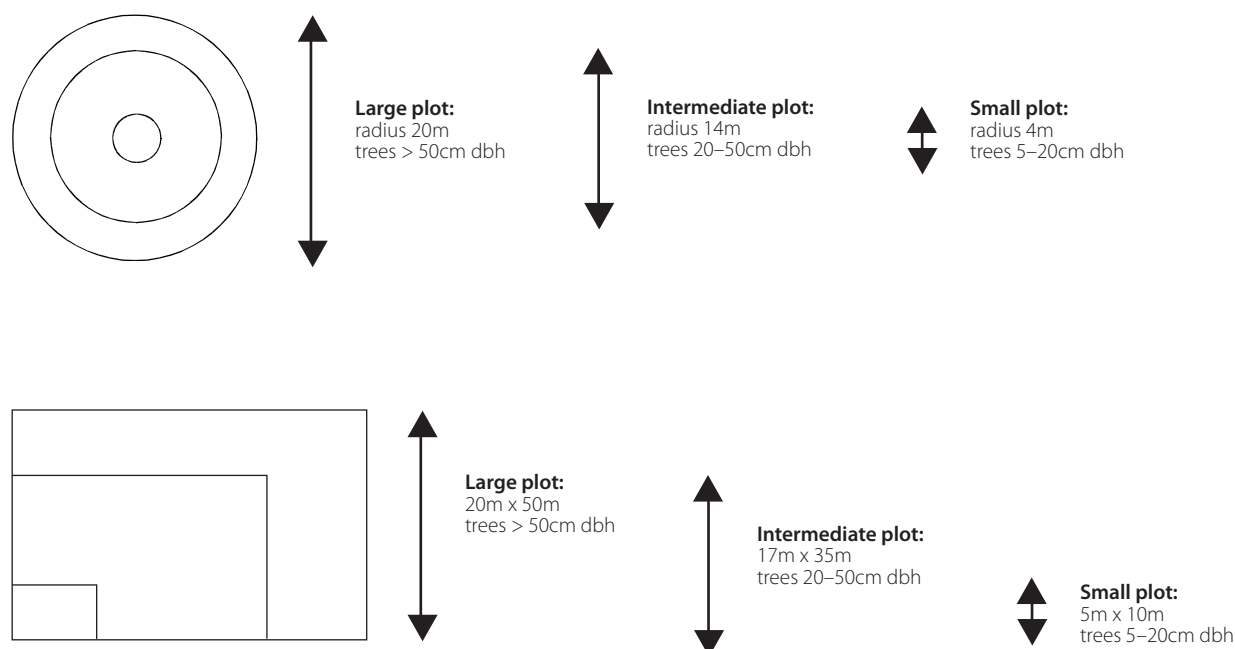
[†] stems < 5cm dbh would only be measured in very young forest.

A single plot can be used just as effectively as a nested design and may be preferred for systems with low variation, such as single species plantations. If a single plot is used, then the plot size should be large enough that at least eight to 10 trees will be measured within the plot boundaries at the end of the project activity. (Therefore, substantially more than eight to 10 trees will be measured per plot at the start of the project activity.)

Data and analyses at the plot level are extrapolated to the area of a full hectare to produce carbon stock estimates. Extrapolation occurs by calculating the proportion of a hectare (10,000 m²) that is occupied by a given plot using expansion factors. As an example, if a series of nested circles measuring 4m, 14m and 20m in radius is used, their areas are equal to 50m², 616m² and 1,257m² respectively (using expansion factors of 198.9 for the smallest plot, 16.2 for the intermediate and 8.0 for the largest to convert the plot data to a hectare basis). Expansion factors are described further in Section 8.

Because all carbon measurements are reported on a horizontal-projection basis, plots on sloping lands must use a correction factor. This correction factor accounts for the fact that when distances measured along a slope are projected to the horizontal

The schematic diagram below represents a three-nest sampling plot in both circular and rectangular forms:



plane, they are smaller. If the plot is split between level and sloping ground, it is simpler to move the plot so that it is either entirely level or sloping. If the plot falls on a slope, then the slope angle should be measured using a clinometer. Where the plot is located on a slope that is greater than 10 per cent, the slope should be quantified so that an adjustment can be made to the plot area at the time of analysis. Details on this calculation are given in Section 8.

6.5.1.2. Non-tree carbon pools

Non-tree carbon pools differ from trees in that it is not physically possible to measure the identical sample at two periods in time. With non-tree vegetation, forest floor and soil, this is because the process of measuring the sample destroys the sample – it is collected, weighed and dried in an oven. With downed dead wood the sample is not necessarily destroyed, but tracking pieces of dead wood between two periods of time is logistically very challenging. Consequently, for each of these pools, the samples are temporary. To maintain statistical independence (an abstract concept that is important to guarantee representative results), the sampling location should be moved at each census.

For the destructively sampled components, the size of the plot should be large enough to capture a sufficiently large sample while still maintaining a high level of sampling efficiency. Typically, for herbaceous vegetation and forest floor, a small sub-plot of between 0.25m² and 0.5m² is used. For shrubs, a larger plot of perhaps 1m² could be used. For soil, typically four 30cm soil cores are pooled to create a single sample for carbon concentration with an additional core for bulk density. Sections 7.3 to 7.6 have more information on carrying out these measurements.

6.5.2. Number of Plots

It is important that sampling is carried out with statistical rigour, as it is likely this will be a requirement of the Designated Operating Entity. In employing this rigour, the first step is identifying the number of plots required to reach the desired precision in the results.

An online tool for calculating number of plots is available at: <http://www.winrock.org/Ecosystems/tools.asp>.

To use the tool, input the desired precision and the number, area, mean carbon density and co-efficient of variation for each strata. With this information, the tool calculates the required number of plots.

To calculate number of plots without the tool, use the following steps:

STEP 1 – Identify the desired precision level.

The level of precision required for a carbon inventory has a direct effect on inventory costs as described above. Accurate estimates of the net change in carbon stocks can be achieved at a reasonable cost to within 10 per cent of the true value of the mean at the 95 per cent confidence level [6]. The level of precision should be determined at the outset – ± 10 per cent of the mean is frequently employed, although a precision as low as ± 20 per cent of the mean could be used. *There are no hard and fast rules for setting the precision level, but the lower the precision, the more difficult it will be to say with confidence that a change in carbon stocks has occurred between two time periods.*

Once the level of precision has been decided upon, sample sizes can be determined for each stratum in the project area. Each carbon pool will have a different variance (that is, amount of variation around the mean). However, experience has shown that focusing on the variance of the dominant carbon pool (for example, trees for forestry activities) captures most of the variance. Even though variation in the other components may be higher, if a high precision is attained in the dominant component, a lack of precision in the other components will not harm the overall results.

STEP 2 – Identify an area to collect preliminary data. For example, if the activity is to afforest agricultural lands and will last for 20 years, then an estimation of the carbon stocks in the trees of about six to 10 plots within an existing 15 to 20-year-old forest would suffice.

Preliminary data are necessary in order to evaluate variance and, from this, the required number of plots for the desired level of precision. Between six to 10 plots is usually sufficient to evaluate variance. If the project consists of multiple strata, preliminary data is required for each stratum.

STEP 3 – Estimate carbon stock, standard deviation and variance from the preliminary data.

STEP 4 – Calculate the required number of plots.

For L strata, the number of plots (n) needed =

$$n = \frac{\left(\sum_{h=1}^L N_h * s_h \right)^2}{\frac{N^2 * E^2}{t^2} + \left(\sum_{h=1}^L N_h * s_h^2 \right)}$$

Where:

E = allowable error or the desired half-width of the confidence interval. Calculated by multiplying the mean carbon stock by the desired precision (that is, mean carbon stock \times 0.1, for 10 per cent precision, or 0.2 for 20 per cent precision),

t = the sample statistic from the t -distribution for the 95 per cent confidence level. t is usually set at 2 as sample size is unknown at this stage,

N_h = number of sampling units for stratum h (= area of stratum in hectares or area of the plot in hectares),

n = number of sampling units in the population ($n = \sum N_h$)

s_h = standard deviation of stratum h .

This equation can be simplified.

For a single-stratum project:

$$n = \frac{(N \times s)^2}{\frac{N^2 \times E^2}{t^2} + N \times s^2}$$

For two strata:

$$n = \frac{((N_1 \times s_1) + (N_2 \times s_2))^2}{\frac{N^2 \times E^2}{t^2} + N_1 \times s_1^2 + N_2 \times s_2^2}$$

The following two examples demonstrate the use of the formula and also illustrate the advantage of stratification. In this example, a 5,000-hectare project area requires 29 plots without stratification to be monitored to high precision, but only 18 plots with stratification.

Single-stratum project

Area	= 5,000 ha
Plot size	= 0.08 ha
Mean stock	= 101.6 t C/ha
Standard deviation	= 27.1 t C/ha
N	= 5,000/0.08 = 62,500
Desired precision	= 10 %
E	= 101.6 \times 0.1 = 10.16

$$n = \frac{(62,500 \times 27.1)^2}{\frac{62,500^2 \times 0.1^2}{2^2} + 62,500 \times 27.1^2}$$

= 29 plots

For three strata:

	Stratum 1	Stratum 2	Stratum 3	Total
Area (ha)	3,400	900	700	5,000
Plot size	0.08	0.08	0.08	0.08
Mean carbon density (t C/ha)	126.6	76.0	102.2	101.6
Standard deviation	26.2	14.0	8.2	27.1
N	3,400/0.08 = 42,500	900/0.08 = 11,250	700/0.08 = 8,750	5,000/0.08 = 62,500
Desired precision (%)				10
E				101.6 × 0.1 = 10.16

$$n = \frac{\frac{62,500^2 \times 10.16^2}{2^2} + (42,500 \times 26.2^2) + (11,250 \times 14.0^2) + (8,750 \times 8.2^2)}{\frac{((42,500 \times 26.2) + (11,250 \times 14) + (8,750 \times 8.2))^2}{2^2}}$$

= 18 plots

The more variable the carbon stocks, the more plots are needed to attain targeted precision levels. However, if a stratified project area requires more measurement plots than an unstratified area, remove one or more of the strata. The purpose of the stratification is to allow more efficient sampling.

If a project site is stratified, the following formula can be used to allocate the calculated number of plots among the various strata:

Number of plots for each stratum:

$$n_h = n \times \frac{N_h \times s_h}{\sum_{h=1}^L N_h \times s_h}$$

Where:

- n = the total number of plots,
 n_h = the number of plots in stratum h ,
 N = the number of sampling units in the population,
 N_h = the number of sampling units in stratum h ,
 s = the standard deviation,
 s_h = the standard deviation in stratum h .

For example, using the data from the calculations above:

Stratum 1

$$n_h = \left[\frac{(42,500 \times 26.2)}{(42,500 \times 26.2) + (11,250 \times 14) + (8,750 \times 8.2)} \right] \times 18$$

= 15 plots

Stratum 2

$$n_h = \left[\frac{(11,250 \times 14)}{(42,500 \times 26.2) + (11,250 \times 14) + (8,750 \times 8.2)} \right] \times 18$$

= 2 plots

Stratum 3

$$n_h = \left[\frac{(8,750 \times 8.2)}{(42,500 \times 26.2) + (11,250 \times 14) + (8,750 \times 8.2)} \right] \times 18$$

= 1 plot

The formulas above can equally be used with non-tree carbon pools or soil. Such plots will be temporary and new random locations should be chosen at each measurement period.

However, since tree biomass will dominate total biomass (and therefore will also dominate the summed variance for the project), it is practical to estimate the number of plots needed for the other carbon pools based loosely on the number of plots for the dominant biomass component. For example, a single 100m line intersect (for downed dead wood, see Section 7.4.2), four clip plots for herbaceous vegetation and the forest floor, and four soil samples would be sufficient per tree plot.

6.5.3. Location of Plots

To maintain statistical rigour, plots must be located without bias. The entirety of the project site should be sampled. If plots follow a road or trail, then all locations in the project do not have an equal chance of selection and a systematic bias has been introduced. Instead, the location of plots should either be random or located using a fixed grid that covers the entire area.

Where multiple carbon pools are measured, it is reasonable to base the location of the secondary pool plots on the location of the original plot for the first census. However, these plots should be outside the original plot and all subsequent remeasurement censuses should occur in a new location.

STEP 1 – Prepare a map of the project, with the project boundaries of strata within the project clearly delineated.

STEP 2 – Decide whether plots will be distributed systematically or randomly.

STEP 3a – The random location of plots can be achieved using random number tables, the random function in Geographic Information Systems programmes or alternatively by using the millisecond counter in a stopwatch to take a random bearing and random distance for assigning plots on the map.

STEP 3b – The systematic location of plots within each stratum can be achieved by overlaying a grid on the project map and allocating plots in a regular pattern across the strata.

6.6. Determine Measurement Frequency

It is recommended that for carbon accumulation, the frequency of measurements should be defined in accordance with the rate of change of the carbon stock.

- Forest processes are generally measured over periods of five-year intervals;
- Carbon pools that respond more slowly, such as soil, are measured every 10 or even 20 years.

As verification and certification must occur every five years for CDM project activities, it is reasonable that at least the dominant biomass pool (trees) should be measured at the same frequency. Indeed, it may not be possible to claim credit for pools not measured with a five-year frequency.

For pools accumulating carbon more slowly (for example, dead wood or soil) it would be logical to measure at time zero and again at the end of the project activity, and to claim credit at this time for all sequestration that has occurred in these pools.

7. FIELD MEASUREMENTS

7.1. Preparation for Fieldwork

Efficient planning for fieldwork is essential to reduce unnecessary labour costs, avoid safety risks and ensure reliable carbon estimates.

The equipment used for fieldwork should be accurate and durable to withstand the rigours of use under adverse conditions. The type of equipment required will depend on the type of measurements. The following list covers most of what is typically used:

– Compass	for measuring bearings
– Fibreglass metre tapes (100m and 30m)	for measuring distances
– Global Positioning System (GPS)	for locating plots
– Plot centre marker (rebar/PVC tubing)	for marking plots
– Metal detector	for locating belowground plot markers
– Aluminium nail and number tags	for marking trees
– Tree diameter at breast height (dbh) tape	for measuring trees
– Clinometers (percent scale)	for measuring tree height and slope
– Coloured rope and pegs or a digital measuring device (DME)	for marking plot boundaries
– 100m line or two 50m lines	for measuring dead wood
– Calipers	for measuring dead wood
– Hand saw	for collecting dead wood samples and cutting destructive samples
– Spring scales (1kg and 300g)	for weighing destructive samples
– Large plastic sheets	for mixing forest floor/understory sample
– Soil sampling probes	for sampling soil
– Rubber mallet	for inserting soil probes
– Cloth (for example, Tyrek) or paper bags	for collecting soil and understory samples

- If trees are to be tagged (see Section 7.2.1), aluminum nails and tags should always be used to avoid rust. If fire is prevalent at the site, use an aluminum nail and a steel tag.
- Plots can be marked either conspicuously (for example, with PVC) or inconspicuously (for example, by sinking iron rods below the ground and navigating to plot using a Global Positioning System and metal detector).
- For square or rectangular plots, mark the four corners of the plots. During the measurement, run flagging tape between the corner markers to delineate the edges.
- A compass with a declination adjustment is preferred, so that accurate and replicable bearings can be taken.
- Dbh tapes are critical when making tree measurements. Steel or aluminum dbh tapes are normally used. Cloth

ones should be avoided as they can stretch and result in inaccurate measurements. Dbh tapes are relatively inexpensive and are readily available from suppliers such as: www.forestry-suppliers.com or www.benmeadows.com.

- For collecting soil samples, cloth bags are preferred as paper ones have a tendency to rip. Do not use plastic bags, as they do not allow for the samples to dry, which can result in increased respiration and inaccurate results.

7.2. Trees, Palms and Lianas

7.2.1. Trees

The biomass and carbon stocks of trees are estimated using appropriate equations applied to the tree measurements. For practical purposes, tree biomass is often estimated from equations that relate biomass to dbh. Although the combination of dbh and height is often superior to dbh alone, measuring tree height can be time-consuming and will increase the expense of any monitoring program. Furthermore, databases of trees from around the world show that highly significant biomass regression equations can be developed with very high accuracy using just dbh. *In forestry, dbh is defined as 1.3m above the ground.*

STEP 1 – Accurately locate the plot centre (use of a GPS is the preferred approach).

STEP 2 – If the plot is permanent, mark the centre (if plot is circular) or the boundaries (if plot is square) – experience has shown metal rods and/or PVC pipe work well. Assign a unique number to the plot.

STEP 3a – Starting at the north of the plot, begin measuring trees. Flag the first tree to mark the start/end point. Measure trees at dbh using the guidance below.

STEP 3b – After measuring a tree, move clockwise to the next tree. If the plots are to be remeasured, tag the trees using an aluminum numbered tag and nail. It is not necessary to record tree species unless species with different forms exist in the same area (for example, pines and broadleaf species, or palms and early colonising species).

Tagging trees

When trees are tagged, the numbered tag and nail should be placed at 10cm below dbh to avoid errors arising from bumps or other imperfections that can develop at the site where the nail enters the tree. In future inventories, the dbh measurement will be taken by measuring 10cm up from the nail. The aluminum nail should be inserted deep enough to hold the tag firmly but with enough nail exposed for the tree to grow. If the trees in the project area will be subjected to harvest in the future, the nail and tag should be placed at the base of the tree to avoid any accidents with chainsaws or other equipment. Each plot should contain a description of the approach that was used, so that future measurements can be completed efficiently and accurately.

STEP 3c – To ensure accurate accounting of ingrowth (that is, trees that grow into the minimum size class of the nested plot), the position of new trees should be recorded at each census with regard to each of the nested plots.

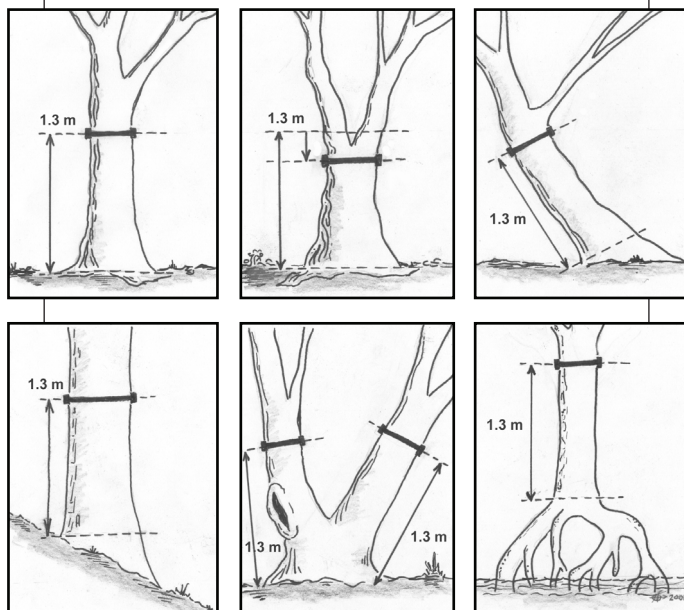
STEP 3d – Occasionally trees will be close to the boundary of a plot. Plots are typically small and will be expanded to estimate biomass carbon on a per hectare basis. It is therefore important to carefully decide if a tree is in or out of a plot. If more than 50 per cent of the trunk is within the plot boundary, the tree is in. If more than 50 per cent of the trunk is outside of the boundary, it is out and should not be measured. If the tree is exactly on the border of the plot, flip a coin to determine if it is in or out.

Using a dbh tape

It is important that a dbh tape is used properly to ensure consistency of measurement:

- Be sure to have a staff or pole measuring 1.3m in length so the dbh location on the tree can be accurately identified, or use a sturdy stick (at least 2cm in diameter). Alternatively, each member of the team should measure the location of dbh (that is, 1.3m above ground) on their own bodies and use that location to determine the placement of the tape.
- Dbh tapes often measure diameter on one side and circumference on the other. It is important that all measurers know which measurements to record.
- If the tree is on a slope, always measure on the uphill side.
- If the tree is leaning, the dbh tape must be wrapped according to the tree's natural angle (not straight across, parallel to the ground).
- If the tree is forked at or below the dbh, measure just below the fork point. If it is impossible to measure below the fork, then measure as two trees. Traditional forestry dictates that forked stems be measured as two separate trees but when the focus is on biomass, it is more accurate to measure as a single tree wherever possible.
- If the tree has fallen but is still alive, then place the measuring stick towards the bottom and measure at dbh just as if the tree was standing upright. Trees are considered alive if there are green leaves present.
- If a liana or vine is growing on a tree that is going to be measured, do not cut the liana to clear a spot to measure

the tree's dbh. If possible, pull the liana away from the trunk and run the dbh tape underneath. If the liana is too big to pull away from the trunk, then use the back of the dbh tape and pull it across the front of the tree and estimate the diameter visually. Cutting a liana from a tree should only be a last resort because, over time and with repeated measurements, interfering with the natural dynamics in the plot can make it different from the surrounding forest. The same standard should be followed for any other type of natural organisms (for example, mushrooms, epiphytes, fungal growths, termite nests, etc.) that are found on the tree.



Dbh measurement locations for irregular and normally shaped trees

Alternative methods for measuring trees exist, including a basal area prism to estimate basal area/volume, which are commonly applied in commercial forestry. Methods are also provided for estimating biomass carbon from volume in the *IPCC Good Practice Guidance on Land Use, Land-Use Change and Forestry* (2003). Unless local volume equations exist, or the project is part of a commercial forestry operation, it is advisable to use the allometric method of directly estimating biomass.

7.2.2. Palms

If palms are present, only the height should be recorded since biomass in palms is more closely related to height than to diameter.

STEP 1 – Determine if palms are present in the intermediate-sized nested plot and if any exceed 1.3m in height.

STEP 2 – For any palms exceeding 1.3m, measure the height using a clinometer (or directly if the palm is only a few metres tall). Measure only the height of the stem, that is, from the base up to the spot where the stem is no longer visible.

STEP 3 – If the plot is to be remeasured, insert an aluminum numbered tag at 10cm below dbh.

7.2.3. Lianas

Lianas are difficult to measure because they are often long and cross the plot in several places. Unless they form a significant component of the ecosystem, they should not be measured because of these problems and also because it is hard to find biomass equations to use with them.

STEP 1 – Determine if lianas are a significant biomass component.

STEP 2 – If necessary, measure at dbh. Take care that the same liana is not measured more than once. Lianas do not normally grow to more than 10cm in diameter, so only measure in the smallest nest.

7.3. Non-Tree Vegetation

Non-tree vegetation is measured by simple harvesting techniques. For herbaceous plants, a square frame (30cm x 30cm) made from PVC pipe is sufficient for sampling. For shrubs and other large non-tree vegetation, larger frames should be used (about 1–2m², depending on the size of the vegetation).

STEP 1 – Place the clip frame at the sampling site. If necessary, open the frame and place around the vegetation.

STEP 2 – Clip all vegetation within the frame to ground level. The frame should be viewed as extending vertically, and any vegetation falling outside the boundaries of the plot (even it begins inside the plot) should be excluded.

STEP 3 – Weigh the sample and remove a well-mixed subsample for determination of dry-to-wet mass ratio. Weigh the subsample in the field, then oven-dry to a constant mass (usually at ~ 70°C).

7.4. Dead Wood

7.4.1. Standing dead wood

Within plots delineated for live trees, standing dead trees should also be measured. The dbh and decomposition state of the dead tree should be recorded. Decomposition classes for standing dead wood are defined practically as follows:

1. Tree with branches and twigs and resembles a live tree (except for leaves);
2. Tree with no twig, but with persistent small and large branches;
3. Tree with large branches only;
4. Bole (trunk) only, no branches.

For classes 2, 3 and 4, the height of the tree and the diameter at ground level should be measured and the diameter at the top should be estimated. Height can be measured using a clinometer.

Top diameter can be estimated using a relascope or through the use of a transparent measuring ruler. Hold the ruler approximately 10–20cm from your eye and record the apparent diameter of the top of the tree. The true diameter is then equal to:

$$\text{True diameter (m)} = \frac{\text{Distance eye to tree (m)}}{\text{Distance eye to ruler (m)}} \times \text{Ruler measurement (m)}$$

Distance can also be effectively measured with a laser range finder.

7.4.2. Downed dead wood

Lying dead wood is most efficiently measured using the line-intersect method [7, 8]. Only coarse dead wood (wood with a diameter > 10cm) is measured with this method – dead wood with a smaller diameter is measured with litter.

STEP 1 – Lay out two lines of 50m either in a single line or at right angles.

STEP 2 – Along the length of the lines, measure the diameter of each intersecting piece of coarse dead wood (> 10cm diameter). Calipers work best for measuring the diameter. A piece of dead wood should only be measured if: (a) more than 50 per cent of the log is aboveground and (b) the sampling line crosses through at least 50 per cent of the diameter of the piece. If the log is hollow at the intersection point, measure the diameter of the hollow; the hollow portion in the volume estimates is excluded.

STEP 3 – Assign each piece of dead wood to one of three density classes – sound, intermediate or rotten. To determine what density class a piece of dead wood fits into, each piece should be struck with a saw or machete. If the blade does not sink into the piece (that is, it bounces off), it is classified as sound. If it sinks partly into the piece and there has been some wood loss, it is classified as intermediate. If the blade sinks into the piece, there is more extensive wood loss and the piece is crumbly, it is classified as rotten.

STEP 4 – Representative dead wood samples of the three density classes, representing the range of species present, should be collected for density (dry weight per green volume) determination. Using a chainsaw or a hand saw, cut a complete disc from the selected piece of dead wood. The average diameter and thickness of the disc should be measured to estimate volume. The fresh weight of the disc does not have to be recorded. The disc should be oven-dried to a constant weight.

7.5. Forest Floor (Litter Layer)

The forest floor, or litter layer, is defined as all dead organic surface material on top of the mineral soil. Some of this material will still be recognisable (for example, dead leaves, twigs, dead grasses and small branches) and some will be unidentifiable decomposed fragments of organic material. Note that dead wood with a diameter of less than 10cm is included in the litter layer.

Litter should be sampled at the identical time of year at each census to eliminate seasonal effects. A square frame (30cm x 30 cm) made from PVC pipe is suitable for sampling.

STEP 1 – Place the sampling frame at the sample site.

STEP 2 – Collect all the litter inside the frame. A knife can be used to cut pieces that fall on the border of the frame. Place all the litter on a tarpaulin beside the frame.

STEP 3a – Weigh the sample on-site, then oven-dry to a constant weight.

STEP 3b – Where sample bulk is excessive, the fresh weight of the total sample should be recorded in the field, and a subsample of manageable size (approximately 80–100g) taken for moisture content determination, from which the total dry mass can be calculated.

7.6. Soil

To obtain an accurate inventory of organic carbon stocks in mineral or organic soil, three types of variables must be measured: (1) depth, (2) bulk density (calculated from the oven-dried weight of soil from a known volume of sampled material), and (3) the concentrations of organic carbon within the sample. For convenience and cost-efficiency, it is advised to sample to a constant depth, maintaining a constant sample volume rather than mass. A 30cm probe is an effective measurement tool.

and then thoroughly mixed. The well-mixed sample should not be oven-dried for the carbon analysis, but only air-dried; however, the carbon concentration does need to be expressed on an oven dry basis at 105°C. The dry combustion method using a controlled-temperature furnace (for example, a LECO CHN-2000 or equivalent) is the recommended method for determining total soil carbon [9] but the Walkley-Black method is also commonly used.

STEP 1 – Steadily insert the soil probe to a 30cm depth.

If the soil is compacted, use a rubber mallet to fully insert. If the probe will not penetrate to the full depth, do not force it as it is likely a stone is blocking its route and, if forced, the probe will be damaged. Instead, withdraw the probe, clean out any collected soil and insert in a new location.

STEP 2 – Carefully extract the probe and place the sample into a cloth bag. Because the carbon concentration of organic materials is much higher than that of the mineral soil, including even a small amount of surface material can result in a serious overestimation of soil carbon stocks.

STEP 3 – To reduce variability, aggregate four samples from each collection point for carbon concentration analysis.

STEP 4 – At each sampling point, take two additional aggregated cores for determination of bulk density. When taking cores for measurements of bulk density, care should be taken to avoid any loss of soil from the cores.

STEP 5 – Soil samples can be sent to a professional laboratory for analysis. Commercial laboratories exist throughout the world and routinely analyse plant and soil samples using standard techniques. It is recommended the selected laboratory be checked to ensure they follow commonly accepted standard procedures with respect to sample preparation (for example, mixing and sieving), drying temperatures and carbon analysis methods.

For bulk density determination, ensure the laboratory dries the samples in an oven at 105°C for a minimum of 48 hours. If the soil contains coarse, rocky fragments, the coarse fragments must be retained and weighed. For soil carbon determination, the material is sieved through a 2mm sieve

8. ANALYSIS

Most calculations determine values for the biomass of a particular carbon pool (except for soil, which usually measures carbon directly). It is common practice to convert biomass to carbon by dividing by two:

$$\text{Carbon} = \frac{\text{Biomass}}{2}$$

However, if local values for the carbon content are available, use these instead. The CDM Executive Board may, in the future, require local measurements of mean carbon content.

Extrapolating carbon stocks from a per plot basis to a per hectare basis requires the use of expansion factors, which indicate the area each sample represents. This standardisation is required so that results can be easily interpreted and also compared to other studies. The first step is to correct for slope so that all carbon values are reported on a horizontal projection.

True horizontal radius is calculated using the formula:

$$L = L_s \times \cos S$$

Where:

- L = the true horizontal plot radius,
- L_s = the standard radius measured in the field along the slope,
- S = the slope in degrees, and
- \cos = the cosine of the angle.

Correcting for slope after returning from the field results in a plot of area:

Circular Plot: Area = π x standard radius (L_s) x slope plot radius (L)

Rectangular Plot: Area = Plot width x calculated true plot length (L)

For example, for a 20m radius plot on a slope of 25 degrees:

$L_s = 20 \times 0.91$ or 18.1m ($0.91 = \cos 25$).

Thus, the plot area = $3.142 \times 20 \times 18.1 = 0.11\text{ha}$.

For a 25m square plot on a slope of 15 degrees:

$L_s = 25 \times 0.97$ or 24.1 m ($0.97 = \cos 15$).

Thus, the area of the plot = $25 \times 24.1 = 0.06\text{ha}$.

All expansion factors referred to from this point on are assumed to use the slope-corrected area of the plot. The expansion factor is calculated as the area of a hectare in square metres divided by the area of the sample in square metres, that is:

$$\text{Expansion factor} = \frac{10,000\text{m}^2}{\text{Area of plot, frame or soil core (m}^2\text{)}}$$

8.1. Live Tree Biomass

Biomass equations relate dbh to biomass. Equations may be for individual species or groups of species, but this literature is inconsistent and incomplete. Before applying a biomass equation, consider its original location, because trees in a similar functional group can differ greatly in their growth form between geographic areas.

STEP 1 – Search for a suitable biomass equation. Either use equations presented here (see Appendix C), search the literature for equations, consult with experts (perhaps in local universities or government forestry departments) or create new equations (see Appendix B).

When making biomass calculations, the given maximum diameter for the equation should be carefully observed. Using equations for trees that exceed the maximum diameters can lead to substantial error (see [10] for ideas on how to address the problem of trees that exceed the size limit of the database).

The biomass equation should be verified for the project site. This can be done simplistically by estimating the volume of the tree stem (see Sections 7.4.1 and 8.4), using a standard factor of 1.2 to include the volume of branches, and multiplying by wood density to attain biomass. Wood density values for most commercially important species are generally available (see [10]) or density can be measured simply. The biomass equation can be verified through comparison with estimations from a range of tree sizes.

The importance of selecting an appropriate equation can be seen from the following example. In Appendix C, two biomass equations are listed for pines in the USA – one for pines in the west and one for pines in the east. For a 50cm dbh tree, the western equation produces a biomass estimate of 1.1 tonnes, while the eastern equation estimates 1.6 tonnes. A 1cm increment from 50cm to 51cm dbh results in a biomass increment of 54kg for the western equation and 77kg for the eastern equation.

STEP 2 – For each tree, calculate biomass using the chosen equation.

For example:

A 55cm dbh tree was measured in moist tropical forest in Bolivia. A general equation for moist tropical forests was chosen (adapted from [10]):

$$\text{Biomass (kg)} = \exp(-2.289 + 2.649 \times \ln dbh - 0.021 \times \ln dbh^2)$$

A 55cm dbh is well within the maximum for this equation (148cm).

1. $2.649 \times \ln(55)$ = 10.615
2. $0.021 \times \ln(55)^2$ = 0.337
3. $-2.289 + 10.615 - 0.337$ = 7.989
4. $\exp(7.989)$ = 2,948.3kg = 2.95 tons of biomass
or 1.47 tons of carbon

STEP 3a – For projects doing a one-time measurement, or for measurements with the purpose of establishing the required number of plots or the baseline carbon stock, sum the biomass of each tree in each nest then multiply by the expansion factor to get biomass per hectare for each nest. Finally, sum the nests to get the total estimated number of tons per hectare for that plot.

STEP 3b – For projects that are tracking the accumulation of carbon in trees, subtract the biomass of a given tree at Time 1 from the biomass of the same tree at Time 2 to get the increment of accumulation.

To be accurate in the calculations of change in carbon stocks, the biomass increment for ingrowth trees (that is, trees that were too small to be measured in the previous census) must be included correctly. To be conservative, the ingrowth tree is assigned the maximum dbh possible for that plot at the previous census. For example, if the minimum diameter for measurement is 10cm and a tree measured for the first time is 12.5cm, at the very least the tree has grown from just less than 10cm to 12.5cm dbh.

Trees that die between censuses are given no increment of growth. They have left the live tree pool and entered the dead tree pool.

Within nests, sum the increments and multiply the sum by the expansion factor. Finally, sum the nests to get the total estimated increment in tons per hectare for that plot. An example is provided overleaf.

Calculating changes in aboveground tree carbon stocks from permanent, nested plots using allometric regression equations

As a hypothetical example, a single plot will be examined. The plot consists of three nested, circular subplots:

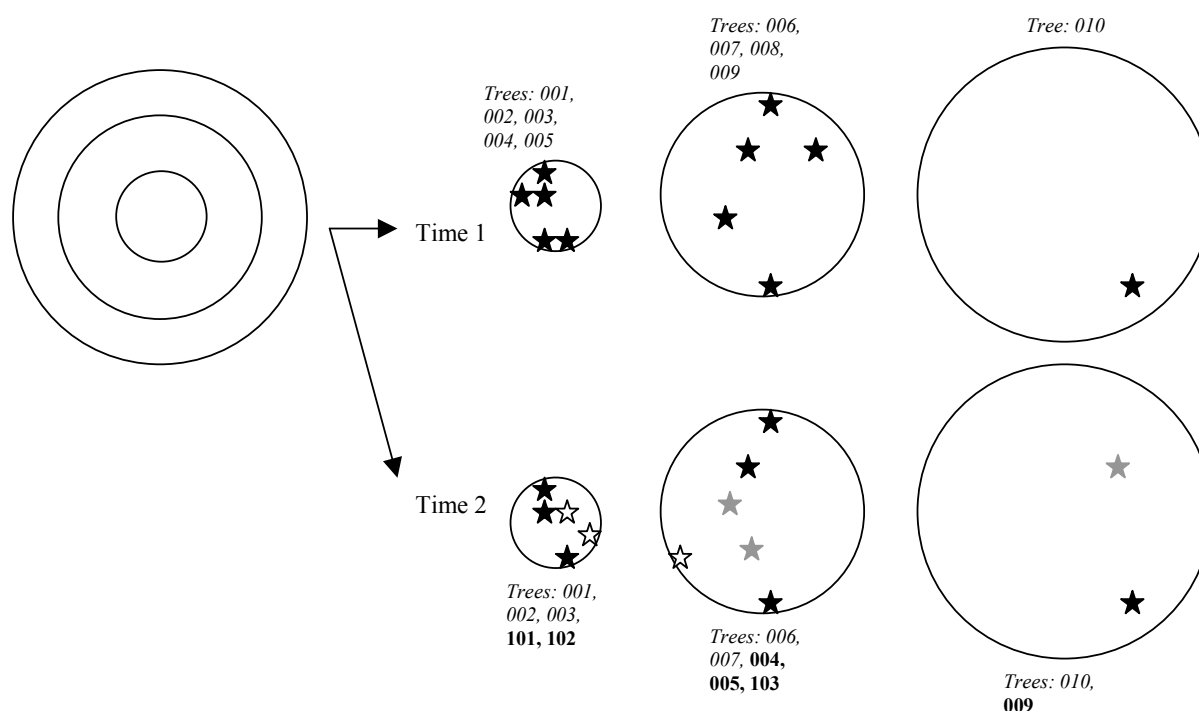
4m radius for trees measuring 5cm to < 20cm dbh

14m radius for trees ≥ 20 cm to < 50cm dbh

20m radius for trees ≥ 50 cm dbh

The figure below and table opposite show measurements over two time periods. Note at Time 2 the ingrowth of trees that were too small to be measured at Time 1 (trees 101 and 102 in the small nest and 103 in the intermediate nest) and outgrowth from one plot size and ingrowth into the next size when the maximum/minimum thresholds are passed (trees 004 and 005 from small to intermediate, tree 009 from intermediate to large).

The stars in the figure indicate the position of trees. At Time 2, the black stars indicate trees that remained in the same size class as at Time 1, the grey stars indicate trees that have grown into the next class, while white stars are trees that have exceeded the measurement minimum for the first time.



TIME 1				TIME 2			
Tag	Nest	Dbh (cm)	Biomass (kg)	Tag	Nest	Dbh (cm)	Biomass (kg)
001	Small	5.6	9.1	001	Small	6.1	11.4
002	Small	8.3	25.1	002	Small	8.9	30.0
003	Small	12.1	65.7	003	Small	13.2	82.0
004	Small	16.2	137.8	004	Intermediate	20.0	234.7
005	Small	18.1	182.4	005	Intermediate	22.1	301.9
006	Intermediate	20.2	240.6	006	Intermediate	20.9	262.2
007	Intermediate	22.3	308.8	007	Intermediate	23.3	344.8
008	Intermediate	38.6	1,221.9	008	DEAD	DEAD	1,221.9
009	Intermediate	48.2	2,124.8	009	Large	51.0	2,444.9
010	Large	57.0	3,222.0	010	Large	58.0	3,364.0
				101	Small	5.5	8.7
				102	Small	5.9	10.5
				103	Intermediate	20.3	243.7

Biomass increment in each subplot =
 $(\Sigma \text{ increments of trees remaining in subplot size class}) +$
 $(\Sigma \text{ increments for outgrowth trees [= } \Sigma \text{ max biomass for size class}$
 $\text{– biomass at Time 1]}) + (\Sigma \text{ increments for ingrowth trees [= } \Sigma \text{ bio-}$
 $\text{mass at Time 2 – min biomass for size class}^\dagger])$

Where Σ = the sum of

† Minimum biomass for each size class is calculated by entering the minimum dbh for that size class into the regression equation (5cm for the small plot, 20cm for the intermediate and 50cm for the large). In this example, 6.8 is the minimum biomass for the small plot, 234.7 for the intermediate and 2,327.5 for the large.

Small subplot = $[(11.4-9.1) + (30.0-25.1) + (82.0-65.7)] + [(234.7-137.8) + (234.7-182.4)] + [(8.7-6.8) + (10.5-6.8)] = 178.3\text{kg}$

Intermediate subplot = $[(262.2-240.6) + (344.8-308.8)] + [(2,327.5-2,124.8)] + [(234.7-234.7) + (301.9-234.7) + (243.7-234.7)] = 336.5\text{kg}$

Large subplot = $(3,364.0-3,222.0) + ((-)) + ((2,444.9-2,327.5)) = 259.4\text{kg}$

Biomass = the sum of biomass in each subplot x expansion factor for that subplot:

Small subplot $178.3 \times 198.9 = 35,463.9 \text{ kg/ha}$
Intermediate subplot $336.5 \times 16.2 = 5,451.3 \text{ kg/ha}$
Large subplot $259.4 \times 8.0 = 2,075.2 \text{ kg/ha}$

Sum = 42,990.4 kg/ha = 43.0 t/ha for the time interval.

For single (non-nested) plots the calculations are more simple. The minimum diameter for measurement must still be tracked but there is no movement of trees between different plot sizes.

8.2. Belowground Tree Biomass

The measurement of aboveground biomass is relatively established and simple. Belowground biomass, however, can only be measured with time-consuming methods. Consequently, it is more efficient and effective to apply a regression model to determine belowground biomass from knowledge of biomass aboveground. The following regression models [11] are widely used:

Boreal:

$$\text{BBD (t/ha)} = \exp(-1.0587 + 0.8836 \times \ln \text{ABD} + 0.1874)$$

Temperate:

$$\text{BBD} = \exp(-1.0587 + 0.8836 \times \ln \text{ABD} + 0.2840)$$

Tropical:

$$\text{BBD} = \exp(-1.0587 + 0.8836 \times \ln \text{ABD})$$

Where:

BBD = belowground biomass density, and

ABD = aboveground biomass density (t/ha)

Applying these equations allows an accurate assessment of belowground biomass. This is the most practical and cost-effective method of determining biomass of roots. *For one-time measurements of root biomass, simply insert the aboveground biomass into the appropriate equation.*

For the calculation of increment in root biomass between two censuses, the exact usage of these equations is important. For tagged trees in permanent plots, it is not possible to simply calculate the total aboveground biomass at Time 1 and Time 2, apply the equations and then divide by the number of years, as this approach cannot account for ingrowth or mortality trees. Instead below-ground biomass increments should be calculated using the following method:

- STEP 1** – Calculate aboveground biomass at Time 1 using allometric equations and the appropriate expansion factors.
- STEP 2** – Calculate the increment of biomass accumulation aboveground between Time 1 and Time 2 (see Section 8.1) and add to the Time 1 total biomass stock for an estimate of aboveground biomass density at Time 2.
- STEP 3** – Apply the appropriate belowground equation to estimate belowground biomass at each time interval.
- STEP 4** – $(\text{Time 2 belowground} - \text{Time 1 belowground}) / \text{number of years} = \text{annual increment of biomass belowground}$.

8.3. Non-Tree Vegetation

- STEP 1** – Calculate the dry mass of the sample. Where a subsample was taken for determination of moisture content:

$$\text{Dry mass} = \left[\frac{\text{subsample dry mass}}{\text{subsample fresh mass}} \right] \times \text{fresh mass of whole sample}$$

- STEP 2** – The biomass density (the number of tons of biomass per hectare) is calculated by multiplying the dry mass by an expansion factor calculated from the sample-frame or plot size.

$$\text{Expansion factor} = \frac{10,000\text{m}^2}{\text{Area of plot (m}^2\text{)}}$$

8.4. Standing Dead Wood

- STEP 1** – For decomposition class 1 (see Section 7.4.1), estimate the biomass of the tree using dbh and an appropriate equation as for live trees.
- STEP 2a** – For class 1, subtract out the biomass of leaves (about 2–3 per cent of aboveground biomass for hardwood/broadleaf species and 5–6 per cent for softwood/conifer species) (e.g., [12]).
- STEP 2b** – For classes 2, 3 and 4, where it is not clear what proportion of the original biomass has been lost, it is the conservative approach to estimate the biomass of just the bole (trunk) of the tree.

Volume is calculated using dbh and height measurements and the estimate of the top diameter. It is then estimated as the volume of a truncated cone.

$$\text{Volume (m}^3\text{) (Class 4)} = \frac{1}{3} \pi h(r_1^2 + r_2^2 + r_1 \times r_2)$$

Where:

- h = the height in metres,
 r_1 = the radius at the base of the tree,
 r_2 = the radius at the top of the tree.

Volume is converted to dry biomass using an appropriate wood density.

Biomass = Volume x Wood density (from samples)

As the wood must be sound to support the still-standing tree, the sound wood density from the downed dead wood measurements (Section 8.5) can be used.

8.5. Downed Dead Wood

- STEP 1** – Calculate the wood density for each density class (sound, intermediate and rotten, see Section 7.4.2) from the pieces of dead wood collected. Density is calculated by the following formula:

$$\text{Density (g/m}^3\text{)} = \frac{\text{mass (g)}}{\text{Volume (m}^3\text{)}}$$

Where:

mass = the mass of the oven-dried sample, and
 $\text{volume} = \pi \times (\text{average diameter}/2)^2 \times \text{average width of the fresh sample}$

Average the densities to get a single density value for each class.

STEP 2 - For each density class, the volume is calculated separately as follows:

$$\text{Volume (m}^3\text{/ha)} = \pi^2 \times \left[\frac{d_1^2 + d_2^2 \dots d_n^2}{8L} \right]$$

where d_1, d_2 etc = diameters of intersecting pieces of dead wood in cm and L = length of the line in m.

STEP 3 – Biomass of lying dead wood (t/ha)
= volume x density.

In the following example, dead wood is sampled along 100m line (using the line-intersect method) to determine biomass density. Diameters and density classes are recorded and a subsample collected to determine density in each of the three density classes (sound, intermediate, and rotten). The following numbers represent the hypothetical results:

13.8 cm sound
10.7 cm sound
18.2 cm sound
10.2 cm intermediate
11.9 cm intermediate
56.0 cm rotten

Densities of subsamples: Sound: 0.43 t/m³
Intermediate: 0.34 t/m³
Rotten: 0.19 t/m³

Volume of sound wood: $\pi^2 \times [d_1^2 + d_2^2 \dots d_n^2 / 8L]$
 $\pi^2 \times [13.8^2 + 10.7^2 + 18.2^2 / 800]$
= 7.85 m³/ha

Volume of intermediate wood: $\pi^2 \times [10.2^2 + 11.9^2 / 800]$
= 3.03 m³/ha

Volume of rotten wood: $\pi^2 \times [56.0^2 / 800]$
= 38.7 m³/ha

Biomass density = (7.85 x 0.43) + (3.03 x 0.34) + (38.7 x 0.19) = 11.8 t/ha

8.6. Forest Floor (Litter Layer)

STEP 1 – Calculate the dry mass of the sample. Where a subsample was taken for determination of moisture content:

$$\text{Dry mass} = \left[\frac{\text{subsample dry mass}}{\text{subsample fresh mass}} \right] \times \text{fresh mass of whole sample}$$

STEP 2 – The biomass density (the number of tons of biomass per hectare) is calculated by multiplying the dry mass by an expansion factor calculated from the sample frame or plot size.

$$\text{Expansion factor} = \frac{10,000 \text{ m}^2}{\text{Area of plot (m}^2\text{)}}$$

8.7. Soil

STEP 1 – Calculate the bulk density of the mineral soil core:

Bulk density (g/m³) =

$$\frac{\text{Oven dry mass (g/m}^3\text{)}}{\text{Core volume (m}^3\text{)} - \left[\frac{\text{Mass of coarse fragments (g)}}{\text{Density of rock fragments (g/m}^3\text{)}} \right]}$$

Where:

The bulk density is for the < 2mm fraction, coarse fragments are > 2 mm. The density of rock fragments is often given as 2.65 g/cm³.

STEP 2 – Using the carbon concentration data obtained from the laboratory, the amount of carbon per unit area is given by:

$$C \text{ (t/ha)} = [(\text{soil bulk density (gm}^3\text{)} \times \text{soil depth (cm)} \times C)] \times 100$$

In this equation, C must be expressed as a decimal fraction – for example, 2.2 per cent carbon is expressed as 0.022 in the equation.

8.8. Estimating Net Change

STEP 1 – If results are initially calculated in tons of biomass per hectare, divide by two to give tons of carbon per hectare.

STEP 2 – The carbon stock for living and standing dead trees, above- and belowground, can be tracked through time for individual plots and the change in carbon stocks calculated directly at the plot level. The change in carbon stocks for the different components should be summed within plots to give a per plot carbon stock change in t C/ha. The plot level results are then averaged to give the mean for the stratum.

STEP 3 – Where soils, downed dead wood, forest floor and non-tree vegetation are included, they have to be calculated differently. The change in carbon stock is calculated by subtracting the mean carbon stock at Time 2 from that at Time 1. The annual increment is then calculated by dividing the change in stocks by the number of years between measurements.

STEP 4 – The results of the various pools are combined to produce an estimate of the total change.

STEP 5 – The baseline is subtracted from the net change in carbon to calculate the net change in carbon stock (or carbon benefit).

STEP 6 – If the project were arranged into multiple strata, then each would be calculated separately as detailed in Steps 1-4 and then combined.

STEP 7 – The mean change in carbon stocks per unit area is then multiplied by the area of the project or entity to produce an estimate of the total change in carbon.

STEP 8 – The total is then converted to tons of CO₂ equivalent by multiplying by 3.67.

8.8.1 Uncertainty

There are two methods for calculating the total uncertainty for a project activity. The first method uses simple error propagation through the root of the sum of the squares of the component errors. The second method uses Monte Carlo simulations to propagate errors. The advantage of the first method is that it is simple to use and requires no additional computer software. However, the second method should ideally be used where:

- Correlations exist between data sets – for example between two carbon pools;
- Uncertainties are very large (greater than 100 per cent).

Method 1 – Simple Error Propagation

STEP 1 – The plot-level results of increment of biomass for living and standing dead trees, above- and belowground, in permanent plots are averaged to give the mean and the 95 per cent confidence intervals for the strata.

STEP 2 – Where temporary plots are used for trees, or the carbon pools of soils, downed dead wood, forest floor or non-tree vegetation are included, the uncertainty has to be calculated differently. The confidence interval is then calculated as:

$$\text{Total 95\% CI} = \sqrt{95\% \text{ CI}_{\text{Time 1}}^2 + 95\% \text{ CI}_{\text{Time 2}}^2}$$

Where:

95% CI_{Time 1} = 95% confidence interval for Time 1, and
95% CI_{Time 2} = 95% confidence interval for Time 2.

STEP 3 – The total confidence interval is calculated as follows:

Total 95% CI =

$$\sqrt{95\% \text{ CI}_{\text{veg}}^2 + 95\% \text{ CI}_{\text{soil}}^2 + 95\% \text{ CI}_{\text{DDW}}^2 + 95\% \text{ CI}_{\text{FF}}^2 + 95\% \text{ CI}_{\text{NTV}}^2}$$

Where:

95% CI_{veg} = 95% confidence interval for vegetation,
95% CI_{soil} = 95% confidence interval for soil, etc., and
DDW = downed dead wood, FF = forest floor and
NTV = non-tree vegetation.

STEP 4 – Ideally, the baseline will also have a 95 per cent confidence interval, in which case the confidence interval after the subtraction of means will equal:

$$\text{Total 95\% CI} = \sqrt{95\% \text{ CI}_{\text{Carbon Stocks}}^2 + 95\% \text{ CI}_{\text{baseline}}^2}$$

STEP 5 – If the project was ordered into multiple strata, then the new confidence interval for the combined strata would be estimated as follows:

$$\text{Total 95\% CI} = \sqrt{95\% \text{ CI}_{s1}^2 + 95\% \text{ CI}_{s2}^2 + \dots + 95\% \text{ CI}_{sn}^2}$$

Where:

95% CI_{s1} = 95% confidence interval for stratum 1,
95% CI_{s2} = 95% confidence interval for stratum 2, etc.,
for all strata (up to n) measured in the project.

STEP 6 – The total uncertainty in carbon stocks per unit area is multiplied by the area of the project or entity to produce an estimate of the total change in carbon.

STEP 7 – The total is then converted to tons of CO₂ equivalent by multiplying by 3.67.

An example of the simple method is given below. In this case, the initial carbon stock in vegetation and soil on the land is assumed to remain constant throughout the estimation period. The baseline only has to be subtracted one time – at subsequent reporting intervals, the gross increment is the net increment.

Calculating net change for the system

The hypothetical example shown is a reforestation project on 500 hectares of degraded cropland. The baseline for carbon stocks in the absence of the project is continued coverage by annual crops with a carbon density of 0.9 t C/ha. The following table reports the carbon increment between years 1 and 10:

Plot Number	Increment in Carbon Pools (t C/ha)			Sum (t C/ha)
	Living Biomass		Dead Organic Matter	
	Aboveground Trees	Belowground	Standing Dead Wood	
Plot 1	12.1	2.4	0.0	14.5
Plot 2	11.5	2.3	0.0	13.8
....
....
Plot 31	12.6	2.5	0.0	15.1
Plot 32	10.9	2.2	0.0	13.1

Mean of summed biomass increment in above- and belowground tree and standing dead wood = 13.8 t C/ha 95% CI = 2.4

+ Increment in non-tree vegetation = 1.8 t C/ha 95% CI = 0.1

+ Increment in downed dead wood = 0.1 t C/ha 95% CI = 0.1

+ Increment in forest floor = 0.2 t C/ha 95% CI = 0.1

+ Increment in soil organic carbon = 0.5 t C/ha 95% CI = 0.1

– Baseline biomass carbon stock = 0.9 t C/ha 95% CI = 0.1

= NET change in carbon stock = 15.5 t C/ha 95% CI = 2.4

Net change in stocks over project area: 15.5 t C/ha x 3.67 t CO₂e/ha / t C/ha x 500ha

± the 95% CI: 2.4 t C/ha x 3.67 t CO₂e/ha / t C/ha x 500ha

Therefore the net change is: 28,443 ± 4,419 t CO₂e over the measurement interval

Method 2 – Monte Carlo Simulations

The principle of Monte Carlo analyses is to perform the summing of uncertainties many times using the uncertain stocks or increments chosen randomly by the computer software from within the distribution of uncertainties that the user initially inputs.

These analyses can be carried out using Monte Carlo software such as Simetar, @Risk or Crystal Ball (www.simetar.com, www.palisade.com/html/risk.asp, www.crystalball.com).

Comparison of two methods for a single dataset

In theory, almost all LULUCF calculations should be performed using Monte Carlo simulations because independence between the various uncertainty values does not exist. For example, Time 1 is always going to be correlated with Time 2 and dead wood stocks are going to be correlated with live tree biomass.

In the following example, calculations are carried out using the two methods outlined here on a single dataset.

Data were collected from 111 plots in closed tropical forest in Belize. The pools sampled included live aboveground trees, standing dead wood, downed dead wood, herbaceous vegetation and litter.

Live aboveground trees:	123.3 t C/ha ± 9.9 (mean ± 95% confidence interval)
Standing dead wood:	3.5 t C/ha ± 1.0
Downed dead wood:	3.9 t C/ha ± 1.1
Herbaceous vegetation:	0.5 ± 0.1
Litter:	2.8 ± 0.3

Propagation of errors

Total stock = 123.3 + 3.5 + 3.9 + 0.5 + 2.8 = 134.0 t C/ha

Uncertainty =

$$\sqrt{9.9^2 + 1.0^2 + 1.1^2 + 0.1^2 + 0.3^2} = 10.0$$

(95 % confidence interval)

Monte Carlo analysis

The data were fit to distribution curves:

Log normal: Live aboveground trees;

Normal: Litter;

Exponential: Standing dead wood, lying dead wood and herbaceous vegetation.

The products of the distributions were modeled through 100 iterations with the following result:

Total stock = 134.6 t C/ha

Uncertainty = 10.1 (95 % confidence interval)

The propagation of errors therefore produced a confidence interval equal to 7.45 per cent of the mean. The equivalent for the Monte Carlo analysis was 7.50 per cent. The confidence intervals differed by 1.1 per cent.

Clearly in the example above, there was little difference between the two methods. However, the measurements were relatively precise for all pools and there was little correlation between pools. Care should be taken when there is a high degree of correlation and/or the measured pools are highly variable.

9. NON-CO₂ GASES

Other gases influence climate change as directly as CO₂. Two gases related to land-use change activities are methane (CH₄) and nitrous oxide (N₂O). Although these gases are produced in smaller quantities than CO₂, their effect for a given mass on global warming is greater. This is illustrated by the calculated global warming potential. Over a 100-year period, CH₄ is expected to have a global warming potential equal to 21 times that of CO₂ and N₂O has a potential equal to 310 times that of CO₂ [1]. Consequently, these gases need only be produced in quantities equal to 4 per cent and 0.3 per cent respectively of the mass of CO₂ emitted to have an equal effect with respect to climate change over 100 years.

CH₄ and N₂O are produced mainly as the result of anthropogenic activities, such as the use of machinery, fires, the draining of wetland regions and the fertilisation of land [1].

Methods for estimating these non-CO₂ greenhouse gas emissions are provided in the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* [13] and the IPCC *Revised 1996 Guidelines for National Greenhouse Gas Inventories* [14]. Tier 1 methods (the most simple ones) are presented here – if any sources are found to be significant (that is, more than 1 per cent of the total), then the users should return consider a Tier 2 or Tier 3 methodology.

9.1 Transport and Machinery

Methods exist for calculating emissions even under Tier 1, but require complex, varied inputs. If gasoline or diesel are consumed heavily as part of project activities, then users should consult the methodology in the IPCC *Revised 1996 Guidelines* [14].

9.2. Fertilisation

If fertilisers are used to enhance tree growth, then N₂O emissions should be considered.

$$\text{Direct N}_2\text{O emissions from fertilisation} = (\text{FSN} \times \text{EF}_1) \times \text{CO}_2\text{EFN}$$

Where:

FSN = Annual amount of synthetic fertiliser nitrogen applied to soils

EF₁ = Emission factor for N₂O emissions from fertilisation in unit of N (default value = 1.25 per cent)

CO₂EFN = CO₂ equivalent factor of 310

9.3. Fire

Biomass burning is the greatest natural (or semi-natural) source of non-CO₂ gas production [13]. The quantity released can be estimated using emission factors based on the quantity of C released [13]. Fire emissions would have to be considered if site preparation for planting involved prescribed burns.

$$\text{CH}_4 \text{ emissions} = \text{Carbon released} \times 0.016 \times \text{CO}_2\text{EFM}$$

Where *CO₂EFM* = CO₂ equivalent factor of 21

$$\text{N}_2\text{O emissions} = \text{Carbon released} \times 0.00011 \times \text{CO}_2\text{EFN}$$

Where *CO₂EFN* = CO₂ equivalent factor of 310

10. QUALITY ASSURANCE AND QUALITY CONTROL

For verifiable and certifiable measurements of changes in carbon stocks, provisions are required for quality assurance (QA) and quality control (QC) to be implemented. A QA/QC plan provides confidence to all stakeholders that the reported carbon credits are reliable and meet minimum measurement standards. The plan should become part of project documentation and cover procedures for: (1) collecting reliable field measurements; (2) verifying laboratory procedures; (3) verifying data entry and analysis techniques; and (4) data maintenance and archiving. To ensure these procedures are carried out in a repeatable manner, a set of Standard Operating Procedures should be prepared for each step.

10.1. QA/QC for Field Measurements

Collecting reliable field measurements is an important step in the QA plan. Those responsible for the carbon measurement work should be fully trained in all aspects of the field data collection and data analyses and Standard Operating Procedures should be followed rigidly to ensure accurate measurement and remeasurement. The Standard Operating Procedures should be detailed enough that any new person sent to the field would be able to accurately repeat the previous measurements. For example, the Standard Operating Procedures should cover all aspects of the field measurements, including steps such as where to measure the dbh of a tree, how to classify dead wood and how to clearly delineate the litter from the mineral soil. The detailed methods presented in this sourcebook are appropriate for creating Standard Operating Procedures for the field phase of a QA/QC plan.

Field crews should receive extensive training so they are fully cognisant of all procedures and understand the importance of collecting data as accurately as possible. An evaluation of the field crews should be conducted to identify errors in field techniques, verify measurement processes and correct any identified problems before they carry out measurements.

A second type of field evaluation should be used to quantify measurement errors. To implement this type of evaluation, a complete remeasurement of a number of plots by people other than the original field crews is performed at the end of the fieldwork. The verifying crew should be experienced in forest measurement and highly attentive to detail. The auditing crew enters the field and remeasures every tree in about 10–20 per cent of the plots. After measurement, a comparison is made with the original data and discrepancies are reverified. Field data collected at this stage can be compared with the original data. Any errors found should be corrected and recorded, and could be expressed as a percentage of all plots that have been rechecked to provide an estimate of the measurement error.

For all the verified plots:

Measurement error (%) =

$$\frac{(\text{Biomass before corrections} - \text{Biomass after corrections})}{\text{Biomass after corrections}} \times 100$$

10.2. QA/QC for Sample Preparation and Laboratory Measurements

Standard operating procedures should also be prepared and rigorously followed for sample preparation and analyses. In many instances, it is likely that commercial laboratories will be used. If so, it is important that their procedures follow accepted standards. For example, soil bulk density samples should be dried at 105°C (221°F) in a drying oven to constant weight. By definition, soil organic carbon is that which passes through a 2mm sieve, thus it is important that the laboratory follow this step. The well-mixed sample should not be oven-dried for the carbon analysis, but only air-dried; however, the carbon concentration does need to be expressed on an oven-dry basis at 105°C (221°F).

For QC, all combustion instruments for measuring carbon should be calibrated using commercially available certified carbon standards. For example, blanks and samples of known carbon concentrations should be analysed in each batch/run. Similarly, all balances for measuring dry weights should be periodically calibrated against known weights. Where possible, 10–20 per cent of the soil samples could be reanalysed/reweighed to produce an error estimate. Similar procedures should be applied to plant material such as litter or understory.

Measurement error (%) =

$$\frac{(\text{Number of errors among checked sample})}{\text{Total number checked}} \times 100$$

If the calculated measurement error is greater than 10 per cent, then rerun all the analyses.

10.3. QA/QC for Data Entry

Field data are either collected directly on electronic media or on field sheets. If entered electronically in the field, then the field data entry step is not needed – however, errors in field data entry can occur and efforts should be made to check this step. If collected on field sheets, the accurate entry of data into the data analysis software is important.

To check for data entry errors, it is suggested that another independent person should enter data from about 10–15 per cent of

the field sheets into the data analysis software. These two data sets can then be compared to check for errors. Any errors detected should be corrected in the master file.

Measurement error (%) =

$$\frac{(\text{Number of errors among checked sample})}{\text{Total number checked}} \times 100$$

If the calculated measurement error is greater than 10 per cent, re-enter the data.

Data analysis software could be developed so that it has checks built into it to highlight potential errors in data entry. For example, such checks could include tests to check that the diameter limits for a given nested plot (if used) is within the limits set by the field work.

Common sense should be used when reviewing the results of the data analysis, to make sure the results fit within the realm of reality. Errors can be reduced if the entered data are reviewed using expert judgment and, if necessary, through comparison with independent data. All personnel involved in measuring and analysing data should communicate closely to resolve any apparent anomalies before final analysis of the monitoring data is completed.

10.4. QA/QC for Data Archiving

Because of the relatively long-term nature of forestry activities, data archiving (maintenance and storage) will be an important component of a project. Copies of all data analyses and models, the final estimate of the amount of carbon sequestered, any GIS products and copies of all measuring and monitoring reports should all be stored in a dedicated and safe place.

Given the time frame over which a project may take place, and the pace of production of updated versions of software and new hardware for storing data, electronic copies of data and reports should be periodically updated or converted to a format that can be accessed by any future software applications.

11. GUIDANCE ON LEAKAGE

Leakage is very difficult to calculate. BioCarbon Fund projects, with their focus on sustainable development, should not be greatly susceptible to leakage as community alternative livelihood programs will automatically be built into projects, diminishing the risk of the local community leaking carbon benefits outside the project boundaries.

Leakage should, however, be considered and here we present a decision tree to determine the importance of leakage on a project-by-project basis. At a simple level, leakage can be split into three categories: **activity shifting**, **market effects** and **super-acceptance**.

Activity shifting occurs when activities that cause emissions are not permanently avoided, but are simply displaced to another area. For example, if one area is set aside for reforestation, cattle farmers who were farming the area might deforest an alternative area outside the project boundaries to replace their lost grazing land.

Market effects occur when emission reductions are countered by emissions created by shifts in supply and demand of the products and services affected by the project. This is of minimal importance for farming activities, but can be important for large-scale commercial timber harvesting. For example, a stop-logging project might decrease the supply of timber, leading other practitioners to increase their rate of harvest. Market effects leakage is not likely to be a problem, however, for afforestation/reforestation project activities.

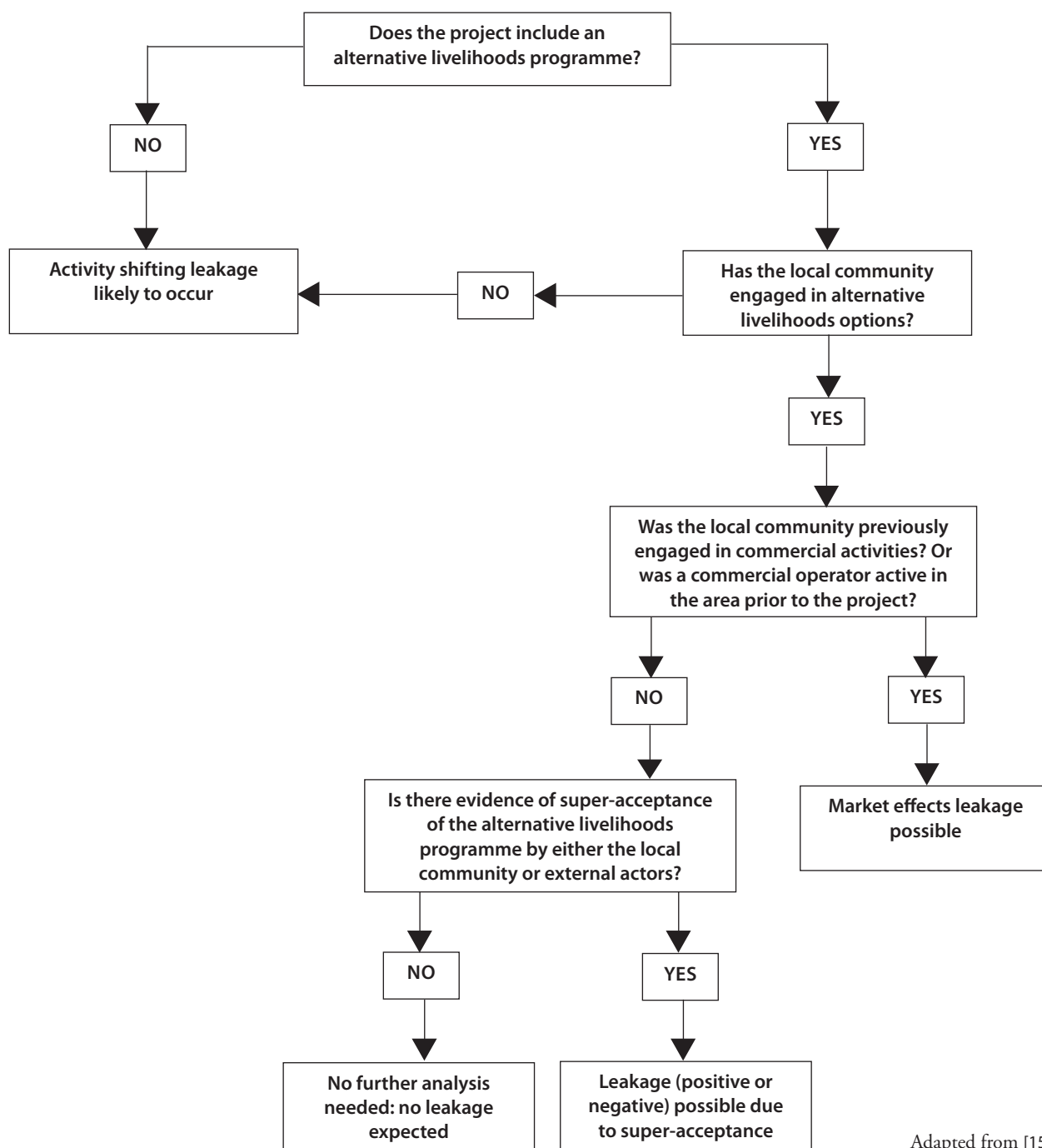
Super-acceptance may result from the alternative livelihoods activities created for the project. If the activities are very successful, they can draw in people from the surrounding regions. The result may be positive¹ or negative leakage. It will be positive if the immigrants were previously deforesting or practising a similarly high greenhouse gas-emitting lifestyle, but negative if the immigrants previously had lower greenhouse gas-emitting lifestyles and now have access to new land, for example, to deforest.

Adapted from [15]

The science of evaluating leakage is not well developed. However if it is suspected that leakage may occur, for example, with displaced farmers cutting forest to replace land that is reforested as part of the project, a significant alternative livelihoods programme could diminish the impact.

The decision tree opposite helps identify whether leakage is likely to occur and what form the leakage might take.

¹ Positive leakage is currently not permitted under the CDM.



Adapted from [15]

12. REFERENCES

- [1] **Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson** (eds). 2001. *Climate Change 2001: The Scientific Basis. Contribution to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, and New York, USA. 881 pp.
- [2] **Dixon, R. K., S. Brown, R. A. Houghton, A. M. Solomon, M. C. Trexler, and J. Wisniewski**. 1994. Carbon pools and flux of global forest ecosystems. *Science* 263: 185-190.
- [3] **Brown, S., J. Sathaye, M. Cannell, and P. Kauppi**. 1996. Management of forests for mitigation of greenhouse gas emissions. Chapter 24 in **R. T. Watson, M.C. Zinyowera, and R.H. Moss** (eds.), *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK, and New York, USA.
- [4] **Dutschke, M, B. Schlamadiner, J. Wong and M. Rumsberg**. 2004. Value and risks of expiring carbon credits from CDM afforestation and reforestation. HWWA Discussion Paper 290. 34 pp.
- [5] **Avery T.E. and H.E. Burkhardt** (eds.). 1994. *Forest Measurements*, 4th edition. McGraw-Hill, New York.
- [6] **Brown, S.** 2002. Measuring, monitoring, and verification of carbon benefits for forest-based projects. *Phil. Trans R. Soc. Lond. A* 360: 1669-1683.
- [7] **Brown, J. K.** 1974. Handbook for inventorying downed woody material. General Technical Report INT-16. Ogden, Utah: USDA Forest Service Intermountain Forest and Range Experiment Station.
- [8] **Harmon, M. E. and J. Sexton**. 1996. Guidelines for Measurements of Woody Detritus in Forest Ecosystems. US LTER Publication No. 20. US LTER Network Office, University of Washington, Seattle, USA.
- [9] **Nelson, D.W., and L.E. Sommers**. 1996. Total carbon, organic carbon, and organic matter. p. 961-1010. In: **D.L. Sparks et al.** (eds.) *Methods of soil analysis. Part 3. Chemical methods*. SSSA, Madison, USA.
- [10] **Brown, S.** 1997. *Estimating Biomass and Biomass Change of Tropical Forests: A Primer*. UN FAO Forestry Paper 134, Rome. 55 pp.
- [11] **Cairns, M. A., S. Brown, E. H. Helmer, and G. A. Baumgardner**. 1997. Root biomass allocation in the world's upland forests. *Oecologia* 111: 1-11
- [12] **Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey**. 2003. National-scale biomass estimation for United States tree species. *Forest Science* 49: 12-35.
- [13] **Namburs, G-J, N.H. Ravindranath, K. Paustian, A. Freibauer, W. Hohenstein and W. Makundi** (eds). 2004. Chapter 3: LUCF Sector Good Practice Guidance. In: **Penman, J, M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe and F. Wagner**. Good Practice Guidance for Land Use, Land-Use Change and Forestry, IPCC National Greenhouse Gas Inventories Programme, Intergovernmental Panel on Climate Change.
- [14] **Intergovernmental Panel on Climate Change**. 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Volumes 1, 2 and 3. Intergovernmental Panel on Climate Change Secretariat, Geneva, Switzerland.
- [15] **Aukland, L., P. Moura Costa and S. Brown**. 2003. A conceptual framework and its application for addressing leakage on avoided deforestation projects. *Climate Policy* 3: 123-136.

APPENDIX A: GLOSSARY

Accuracy: how close a measurement is to its true value.

Activity shifting: when activities that cause greenhouse gas emissions are not permanently avoided through project implementation, but are instead displaced to another area causing carbon leakage (see Section 11 for more information).

Baseline: the emission or removal of greenhouse gases that would occur without the project.

Biomass: organic material (above- or belowground, live or dead).

Boreal: mean annual temperature of less than 0°C.

Carbon pool: organic material containing carbon.

Carbon stock: the quantity of carbon in a given pool or pools per unit area.

Confidence interval: a measure of the spread of the data. It gives a range of values in which there is a percentage probability (usually 95 per cent) of the true mean occurring. Calculated by multiplying the standard error by the appropriate t value. T values for calculating the 95 per cent confidence interval are given below.

Number of Observations	t value	Number of Observations	t value
5	2.776	60	2.001
10	2.262	65	1.998
15	2.145	70	1.995
20	2.093	75	1.993
25	2.064	80	1.990
30	2.045	90	1.987
35	2.032	100	1.984
40	2.023	110	1.982
45	2.015	120	1.980
50	2.010	150	1.976
55	2.005	200	1.972

Cropland: defines any land on which non-timber crops are grown. This includes both herbaceous crops and higher carbon-content systems including vineyards and orchards.

diameter at breast height (dbh): tree diameter parallel to the ground at 1.3m above the ground. Usually measured using a dbh tape, which is calibrated to diameter when the user measures the circumference of the tree.

Forests: includes all land with a canopy cover greater than 30 per cent. This can include natural forest, plantations, forested wetlands and mangroves.

Grazing land: a very broad category that includes managed pastures, prairies, steppe and savannas. Grazing lands will often include trees, but only when the canopy cover is less than 30 per cent. Aquatic systems, such as flooded grasslands and salt marshes, are also included in this category.

Greenhouse gases: gases in the atmosphere (both natural and anthropogenic) that absorb and emit radiation. This property of the gases causes the greenhouse effect. The primary gases in the earth's

atmosphere are water vapour, carbon dioxide, nitrous oxide, methane and ozone.

Hardwoods: this botanical group of trees has broad leaves and produces a fruit or nut.

Leakage: the loss of carbon outside the boundaries of the project as a result of project activities. There are three categories of leakage: activity shifting, market effects and super-acceptance.

Market effects: when emission reductions under a project are countered by emissions created by shifts in supply and demand of the products and services affected by the project (see Section 11 for more information).

Mean: is the sum of observations divided by the number of observations. Mean is calculated in Microsoft Excel using: =AVERAGE (...list of observations...).

Precision: the repeatability of a measure or the range of value between which the true value may lie.

Sequestration: the process of increasing the carbon stock in an ecosystem.

Softwoods: softwoods and conifers (from the Latin word meaning cone-bearing) have needles.

Standard deviation: a measure of the spread of the data. It is calculated in Microsoft Excel using: =STDEV (...list of observations...).

Standard error: a measure of the spread of the data. It is calculated by dividing the standard deviation by the square root of the number of observations.

Super-acceptance: occurs when alternative livelihoods activities created for a project are very successful and draw in people from the surrounding regions. The result may be a positive or negative carbon leakage (see Section 11 for more information).

Temperate: mean annual temperature between 0°C and 20°C.

Tropical: mean annual temperature greater than 20°C.

Variance: a measure of the spread of the data. It is calculated in Microsoft Excel using: =VAR (...list of observations...).

Without-project scenario: see baseline.

APPENDIX B: CREATING BIOMASS REGRESSION EQUATIONS

Method 1: Developing Biomass Equations

Developing local biomass equations can be a resource-expensive operation. When dealing with native forests, it is highly likely that general equations exist (such as those in Appendix C). However, for many multi-purpose species, this may not be the case and it is necessary to develop local biomass equations. Procedures for developing location- and species-specific biomass equations involves the following steps:

- STEP 1** – Select the dominant tree species.
- STEP 2** – Select about 30 trees to represent the full range of diameter classes existing or expected, but with a bias towards large trees (which will dominate biomass).
- STEP 3** – Measure dbh and height of each tree.
- STEP 4** – Harvest the selected trees to the ground.
- STEP 5** – Cut the trees into appropriate sizes to directly estimate their fresh mass.
- STEP 6a** – If cutting a large tree trunk for weighing is not feasible, estimate the volume using data on diameter at both ends of the trunk and the length of the trunk ($Volume = \pi r_1^2 + \pi r_2^2]/2 \times L$), where r_1 = radius at one end of the trunk, r_2 = radius at the other end of the trunk and L = length of the trunk
- STEP 6b** – Collect a complete cross-sectional sample of fresh wood from each log, estimate the volume, oven-dry it and measure the dry mass. Estimate the density (g/cm^3) by dividing the dry mass by its volume.
- STEP 6c** – Estimate mass of trunk using volume and wood density ($Mass = Volume \times Density$) and add to the other components (for example, branches, leaves, etc.) to obtain total mass of the tree.
- STEP 7** – Develop biomass equations linking tree biomass data to dbh alone, or dbh and height.

Simple equations can be created by fitting a regression line to the data in the graphing feature of Microsoft Excel. Methods for developing the linear or non-linear biomass equations using data on dbh, height and mass of trees are given in most text books on statistics or forest mensuration. Further discussion regarding development of biomass equations and their use can be found in Brown (1997) and Parresol (1999).

One of the limitations of this method is that harvesting of about 30 trees of a given species may not be feasible or permitted, except for plantation species.

Method 2: Mean Tree Biomass Estimate

To avoid felling a large number of trees (>30) and the cost of estimating their mass, the mean tree biomass method is an option, although this method is not as accurate as the species-specific biomass equation derived using Method 1.

- STEP 1** – Using dbh data from field measurements, prepare frequency tables using appropriate class intervals (for example, 5cm for each tree species). The smaller the class interval, the lower the error.
- STEP 2** – Locate a tree with a dbh close to the mean dbh value in the forest or plantation for each class.
- STEP 3** – Harvest the selected tree and estimate the mass using the dry mass estimation described in Method 1.
- STEP 4** – Estimate the total mass of all trees in each dbh class using the mass of the tree with mean dbh and the number of trees in the dbh class.

Below is an illustrative example of the mean tree dbh method for estimating aboveground biomass in moist tropical forest.

Dbh class (cm)	Mean Dbh (cm)	Mean mass of tree (kg/tree)	No. of trees/ha	Total biomass (dry mass kg/ha)
5-10	8	23	5	115
10-15	12.5	73	25	1,834
15-20	18	190	20	3,797
20-25	24	402	15	6,028
25-30	28	601	8	4,805
>30	33	922	5	4,609

References

- Brown, S.** 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134, Rome, Italy.
- Parresol, B.R.** 1999. Assessing tree and stand biomass: a review with examples and critical comparisons. *Forest Science* 45, 573-593.

APPENDIX C: PUBLISHED BIOMASS REGRESSION EQUATIONS

Some examples of biomass equations are presented below. For more sources of equations, review:

- IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm)
- Winrock International Ecosystem Services website (<http://www.winrock.org/Ecosystems/publications.aspm>)

Temperate equations

General Classification	Species Group	Equation	Source	Data originating from	Max dbh
Hardwood	General	$\text{Biomass} = 0.5 + ((25000 \times \text{dbh}^{2.5}) / (\text{dbh}^{2.5} + 246872))$	Schroeder et al. (1997)	Eastern USA	85.1cm
Softwood	Pine	$\text{Biomass} = 0.887 + ((10486 \times \text{dbh}^{2.84}) / (\text{dbh}^{2.84} + 376907))$	Brown and Schroeder (1999)	Eastern USA	56.1cm
Softwood	Fir/spruce	$\text{Biomass} = 0.357 + ((34185 \times \text{dbh}^{2.47}) / (\text{dbh}^{2.47} + 425676))$	Brown and Schroeder (1999)	Eastern USA	71.6cm
Hardwood	General	$\text{Biomass} = \text{Exp}(-2.9132 + 0.9232 \times \ln(\text{dbh}^2 \times \text{height}))$	Winrock	Eastern USA	85.1cm
Hardwood	Aspen/alder/ cottonwood/ willow	$\text{Biomass} = \text{Exp}(-2.2094 + 2.3867 \times \ln \text{dbh})$	Jenkins et al. (2003)	USA	70cm
Hardwood	Soft maple/ birch	$\text{Biomass} = \text{Exp}(-1.9123 + 2.3651 \times \ln \text{dbh})$	Jenkins et al. (2003)	USA	66cm
Hardwood	Mixed hardwood	$\text{Biomass} = \text{Exp}(-2.4800 + 2.4835 \times \ln \text{dbh})$	Jenkins et al. (2003)	USA	56cm
Hardwood	Hard maple/oak/ hickory / beech	$\text{Biomass} = \text{Exp}(-2.0127 + 2.4342 \times \ln \text{dbh})$	Jenkins et al. (2003)	USA	73cm
Softwood	Cedar/larch	$\text{Biomass} = \text{Exp}(-2.0336 + 2.2592 \times \ln \text{dbh})$	Jenkins et al. (2003)	USA	250cm

General Classification	Species Group	Equation	Source	Data originating from	Max dbh
Softwood	Douglas-fir	$\text{Biomass} = \text{Exp}(-2.2304 + 2.4435 \times \text{Indbh})$	Jenkins et al. (2003)	USA	210cm
Softwood	True fir/hemlock	$\text{Biomass} = \text{Exp}(-2.5384 + 2.4814 \times \text{Indbh})$	Jenkins et al. (2003)	USA	230cm
Softwood	Pine	$\text{Biomass} = \text{Exp}(-2.5356 + 2.4349 \times \text{Indbh})$	Jenkins et al. (2003)	Western USA	180cm
Softwood	Spruce	$\text{Biomass} = \text{Exp}(-2.0773 + 2.3323 \times \text{Indbh})$	Jenkins et al. (2003)	Western USA	250cm
Woodland	Juniper/oak/mesquite	$\text{Biomass} = \text{Exp}(-0.7152 + 1.7029 \times \text{Indbh})$	Jenkins et al. (2003)	USA	78cm
Hardwood	Beech	$\text{Biomass} = \text{Exp}(-3.0366 + 2.5395 \times \text{Indbh})$	Joosten et al. (2004)	Germany	~ 70cm
Softwood	Scots Pine	$\text{Biomass} = 0.152 \times \text{dbh}^{2.234}$	Xiao and Ceulemans (2004)	The Netherlands	9.87cm

Tropical equations

General Classification	Species Group	Equation	Source	Data originating from	Max dbh
Dry (900–1500mm rainfall)	General	$\text{Biomass} = 0.2035 \times \text{dbh}^{2.3196}$	Brown (unpublished)		63cm
Dry (< 900mm rainfall)	General	$\text{Biomass} = 10^{(-0.535 + \log_{10} \text{basal area})}$	Brown (1997)	Mexico	30cm
Moist (1500–4000mm rainfall)	General	$\text{Biomass} = \exp(-2.289 + 2.649 \times \ln \text{dbh} - 0.021 \times \ln \text{dbh}^2)$	Brown (1997, updated)		148cm
Wet (> 4000mm rainfall)	General	$\text{Biomass} = 21.297 - 6.953 \times \text{dbh} + 0.740 \times \text{dbh}^2$	Brown (1997)		112cm
Cecropia	<i>Cecropia</i> species	$\text{Biomass} = 12.764 + 0.2588 \times \text{dbh}^{2.0515}$	Winrock	Bolivia	40cm
Palms	Palms (<i>asai</i> and <i>pataju</i>)	$\text{Biomass} = 6.666 + 12.826 \times \text{height}^{0.5} \times \ln(\text{height})$	Winrock	Bolivia	33m height
Palms	Palms (<i>motacu</i>)	$\text{Biomass} = 23.487 + 41.851 \times (\ln(\text{height}))^2$	Winrock	Bolivia	11m height
Lianas	Lianas	$\text{Biomass} = \exp(0.12 + 0.91 \times \log(\text{BA at dbh}))$	Putz (1983)	Venezuela	12cm

Agroforestry equations

General Classification	Species Group	Equation	Source	Data originating from	Max dbh
Agroforestry Shade Trees	All	$\text{Log}_{10}\text{Biomass} = -0.834 + 2.223 (\text{log}_{10}\text{dbh})$	Segura et al. (2006)	Nicaragua	44cm
Agroforestry Shade Trees	<i>Inga spp.</i>	$\text{Log}_{10}\text{Biomass} = -0.889 + 2.317 (\text{log}_{10}\text{dbh})$	Segura et al. (2006)	Nicaragua	44cm
Agroforestry Shade Trees	<i>Inga punctata</i>	$\text{Log}_{10}\text{Biomass} = -0.559 + 2.067 (\text{log}_{10}\text{dbh})$	Segura et al. (2006)	Nicaragua	44cm
Agroforestry Shade Trees	<i>Inga tonduzzi</i>	$\text{Log}_{10}\text{Biomass} = -0.936 + 2.348 (\text{log}_{10}\text{dbh})$	Segura et al. (2006)	Nicaragua	44cm
Agroforestry Shade Trees	<i>Juglans olanchama</i>	$\text{Log}_{10}\text{Biomass} = -1.417 + 2.755 (\text{log}_{10}\text{dbh})$	Segura et al. (2006)	Nicaragua	44cm
Agroforestry Shade Trees	<i>Cordia alliodora</i>	$\text{Log}_{10}\text{Biomass} = -0.755 + 2.072 (\text{log}_{10}\text{dbh})$	Segura et al. (2006)	Nicaragua	44cm
Shade grown coffee	<i>Coffea arabica</i>	$\text{Biomass} = \exp(-2.719 + 1.991 (\ln(\text{dbh})))$ ($\text{log}_{10}\text{dbh}$)	Segura et al. (2006)	Nicaragua	8cm
Pruned coffee	<i>Coffea arabica</i>	$\text{Biomass} = 0.281 \times \text{dbh}^{2.06}$	Van Noordwijk et al. (2002)	Java, Indonesia	10cm
Banana	<i>Musa X paradisiaca</i>	$\text{Biomass} = 0.030 \times \text{dbh}^{2.13}$	Van Noordwijk et al. (2002)	Java, Indonesia	28cm
Peach palm	<i>Bactris gasipaes</i>	$\text{Biomass} = 0.97 + 0.078 \times \text{BA} - 0.00094 \times \text{BA}^2 + 0.0000065 \times \text{BA}^3$	Schroth et al. (2002)	Amazonia	2–12cm
Rubber trees	<i>Hevea brasiliensis</i>	$\text{Biomass} = -3.84 + 0.528 \times \text{BA} + 0.001 \times \text{BA}^2$	Schroth et al. (2002)	Amazonia	6–20cm
Orange trees	<i>Citrus sinensis</i>	$\text{Biomass} = -6.64 + 0.279 \times \text{BA} + 0.000514 \times \text{BA}^2$	Schroth et al. (2002)	Amazonia	8–17cm
Brazil nut trees	<i>Bertholletia excelsa</i>	$\text{Biomass} = -18.1 + 0.663 \times \text{BA} - 0.000384 \times \text{BA}^2$	Schroth et al. (2002)	Amazonia	8–26cm

References

Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134, Rome, Italy.

Brown, S.L. and P.E. Schroeder. 1999. Spatial patterns of above ground production and mortality of woody biomass for eastern US forests. *Ecological Applications* 9: 968-980. (errata: Brown, S.L., Schroeder, P.E. 2000. *Ecological Applications* 10: 937).

Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey. 2003. National-scale biomass estimation for United States tree species. *Forest Science* 49: 12-35.

Joosten, R., J. Schumacher, C. Wirth and A. Schulte. 2004. Evaluating tree carbon predictions for beech (*Fagus sylvatica* L.) in western Germany. *Forest Ecology and Management* 189: 87-96.

van Noordwijk, M., S. Rahayu, K. Hairiah, Y.C. Wulan, A. Farida and B. Verbist. 2002. Carbon stock assessment for a forest-to-coffee conversion landscape in Sumber-Jaya (Lampung, Indonesia): from allometric equations to land use analysis. *Science in China C* 45 suppl: 75-86. Available at: [http://www.globalcarbonproject.org/PRODUCTS/Table_of_contents_land_use%20\(Canadell_Zhou_Noble2003\)/Noordwijk_yc0075.pdf](http://www.globalcarbonproject.org/PRODUCTS/Table_of_contents_land_use%20(Canadell_Zhou_Noble2003)/Noordwijk_yc0075.pdf).

Putz, F.E. 1983. Liana biomass and leaf area of a 'Tierra Firme' forest in the Rio Negro Basin, Venezuela. *Biotropica* 15: 185-189

Schroeder, P., S. Brown, J. Mo, R. Birdsey and C. Cieszewski. 1997. Biomass estimation for temperate broadleaf forests of the United States using inventory data. *Forest Science* 43: 424-434.

Schroth, G., S.A. D'Angelo, W.G. Teixeira, D. Haag and R. Lieberei. 2002. Conversion of secondary forest to agroforestry and monoculture plantations in Amazonia: consequences for biomass, litter and soil carbon stock after 7 years. *Forest Ecology and Management* 163: 131-150.

Segura, M., M. Kanninen and D. Suárez. 2006. Allometric models for estimating aboveground biomass of shade trees and coffee plants in agroforestry systems in Matagalpa, Nicaragua. Submitted to *Agroforestry Systems*.

Xiao, C-W and R. Ceulemans. 2004. Allometric relationships for below- and aboveground biomass of young Scots pine. *Forest Ecology and Management* 203: 177-186.

APPENDIX D: CHECKLIST FOR CDM AFFORESTATION / REFORESTATION PROJECTS

Author: Igino M. Emmer with support from Wolfram Kägi (BSS)



This checklist can be used during both Project Idea Note and Project Design Document writing stages for either small-scale or normal-sized afforestation/reforestation CDM project activities. Issues and activities for the Project Idea Note are indicated with an asterix; those for small-scale or normal project activities are indicated with an “S” or “N” respectively.

Information sources, formats to be used and issues to be addressed or demonstrated are also identified in the comments column. In certain cases, topics are elaborated in more detail in a dedicated text box.

While this checklist gives general guidance to developing afforestation/reforestation CDM project activities, in specific areas more detailed information is provided, based on the growing experience with the approval procedure for baseline and monitoring methodologies. By no means does this checklist intend to cover all aspects of CDM afforestation/reforestation project development.

A basic knowledge of the UNFCCC and the CDM is assumed, although references to essential documentation are also provided.

Main themes

1. Capacity – knowledge of the process
2. Participation requirements
3. Baseline methodology
4. Monitoring methodology and monitoring plan
5. Project Design Document
6. Legal issues

Glossary of terms

AE	Applicant Entity
AR or A/R	Afforestation or reforestation
CDM	Clean Development Mechanism
CDM AR WG	CDM Working Group for A/R
CDM-AR-NMB	CDM A/R New Baseline Methodology form
CDM-AR-NMM	CDM A/R New Monitoring Methodology form
CDM-AR-PDD	CDM A/R PDD form
CDM-SSC-AR-PDD	CDM Small-Scale A/R PDD form
CER	Certified Emission Reduction
COP	Conference of the Parties to the UNFCCC
DNA	Designated National Authority
DOE	Designated Operational Entity
EB	Executive Board
EB21	21st meeting of the Executive Board
GHG	Greenhouse gas
GPG	Good Practice Guidance
IPCC	Intergovernmental Panel on Climate Change
ICER	Long-term CER
MA	Marrakech Accords
MOP	Meeting of the Parties (to the Kyoto Protocol)
NM	New methodology
NMB	New baseline methodology
NMM	New monitoring methodology
ODA	Official Development Assistance
PDD	Project Design Document
PIN	Project Idea Note
SSC	Small scale
tCER	Temporary CER
UNFCCC	United Nations Framework Convention on Climate Change
VER	Verified Emission Reduction

COP decisions from the checklist

11/CP.7: <http://unfccc.int/resource/docs/cop7/13a01.pdf#page=54>

(Land use, land-use change, and forestry)

17/CP.7: <http://unfccc.int/resource/docs/cop7/13a02.pdf#page=20>

(Modalities and procedures for a Clean Development Mechanism as defined in Article 12 of the Kyoto Protocol)

18/CP.9: <http://unfccc.int/resource/docs/cop9/06a02.pdf#page=5>

(Guidance to the Executive Board of the Clean Development Mechanism)

19/CP.9: <http://unfccc.int/resource/docs/cop9/06a02.pdf#page=13>

(Modalities and procedures for afforestation and reforestation project activities under the Clean Development Mechanism in the first commitment period of the Kyoto Protocol)

14/CP.10: <http://unfccc.int/resource/docs/cop10/10a02.pdf#page=26>

(Simplified modalities and procedures for small-scale afforestation and reforestation project activities under the clean development mechanism in the first commitment period of the Kyoto Protocol and measures to facilitate their implementation)

Checklist for Afforestation/Reforestation CDM project activities

² Requirement / activity	PIN ³	Scale ⁴	Reference ⁵	Sourcebook Section	Comment
CAPACITY – KNOWLEDGE OF THE PROCESS					
A/R CDM project activity cycle (general) and (A/R) CDM modalities	*	N/S	11/CP.7; 17/CP.7; 19/CP.9	S2	http://cdm.unfccc.int/Projects/pac/index.html http://cdm.unfccc.int/Projects/pac/pac_ar.html http://unfccc.int/documentation/decisions/items/2964.php
Steps towards CDM registration		N/S	19/CP.9 G		Text box 1
PARTICIPATION REQUIREMENTS					
Host country must be Party to Kyoto Protocol	*	N/S	17/CP.7 F.30		http://unfccc.int/files/essential_background/kyoto_protocol/application/pdf/kpstats.pdf
DNA must have been established	*	N/S	17/CP.7 F.29		Text box 1
DNA must have selected a definition of 'forest'	*	N/S	19/CP.9 F	\$5.3	Text box 2
DNA must have formulated sustainable development criteria	*	N/S	17/CP.7 G.40		Text box 3
Written approval from DNA for the A/R CDM project activity		N/S	17/CP.7 G.40		Text boxes 1 and 3
Voluntary participation	*	N/S	19/CP.9 G.15a		Text box 1
ODA eligibility	*	N/S	17/CP.7		See 'Baseline methodology – Additionality'
Eligibility of projects that already started implementation		N/S			See 'Project Design Document – Crediting period'
Eligible A/R CDM project activities	*	N/S			See 'Baseline methodology'
Eligibility of land – '31 December 1989 rule'	*	N/S			See 'Baseline methodology'

² Check when completed.³ Asterix (*) indicates that this step is required for the Project Idea Note (PIN).⁴ N = normal/standard CDM project, S = small-scale project, N/S = applies to both normal and small-scale projects.⁵ Reference to relevant COP decision.

Requirement / activity	PIN	Scale	Reference	Sourcebook Section	Comment
Maximum 8000 t CO ₂ -e/y on average over 5 years	*	S	19/CP.9 A.1i		Text box 4
Not de-bundled: multiple project sites at least 1 km apart	*	S	14/CP.10 C		Text box 4
BASELINE METHODOLOGY					
Check for relevant guidelines and instructions of EB		N/S			http://cdm.unfccc.int/EB/Meetings ; http://cdm.unfccc.int/EB/Meetings/021/eb21repan18.pdf
Use existing approved or nearly approved baseline methodologies, if appropriate		N			Text box 5; http://cdm.unfccc.int/methodologies/ARmethodologies
Use existing approved or nearly approved simplified baseline methodologies for small-scale activities, if appropriate		S			Text boxes 4 and 5; http://cdm.unfccc.int/methodologies
Submit for approval if new (simplified) methodology	N/S	EB21; EB22		\$5.6	Text box 5; CDM-AR-NM form at: http://cdm.unfccc.int/EB/Meetings/022/eb22_repan14.pdf ; See also: http://cdm.unfccc.int/EB/Meetings/021/eb21repan18.pdf ; http://cdm.unfccc.int/methodologies/Reference/Documents
Eligible A/R CDM project activities	*	N/S	19/CP.9 F	\$5.1	Text box 2
Eligibility of land – '31 December 1989 rule'	*	N	11/CP.7 A.1c; EB22	\$5.2	Text box 2; http://cdm.unfccc.int/EB/Meetings/022/eb22_repan16.pdf ;
Eligibility of land – '31 December 1989 rule'	*	S			Text boxes 2 and 4; Attachment A in: http://cdm.unfccc.int/Panels/ar/ARWG06_repan2_AR_SSC_Meth.pdf ,
Appropriate use of definitions		N/S	19/CP.9 A; EB21		Text box 6; http://cdm.unfccc.int/EB/Meetings/021/eb21repan19.pdf
Accuracy, assessment of uncertainties, substantiation of conservative approach				\$6.1	Text box 6
Selection of baseline approach	*	N/S	19/CP.9 G.22	\$4.2/5.4	Text box 7
Accounting for non-CO ₂ gases		N	11/CP.7 E21; 19/CP.9 A1	\$9	Text box 8

Requirement / activity		PIN	Scale	Reference	Sourcebook Section	Comment
Accounting for CO ₂ only			S			Text box 4
Ecosystem compartments in soil and biomass included			N	19/CP.9 G.21	\$6.4/9	Text box 8
Only above- and belowground biomass included			S			Text box 4
Project boundary definition		*	N/S	19/CP.9	\$6.2	See 'Leakage'
Compliance with national policies			N/S			
Additionality – qualitative and quantitative		*	N		\$4.1/5.3	Text box 9; Additionality tool for CDM A/R; http://cdm.unfccc.int/EB/Meetings/021/eb21repan16.pdf
Additionality – qualitative and quantitative		*	S			Text box 9; Additionality assessment method; http://cdm.unfccc.int/Panels/ar/ARWG06_repan2_AR_SSC_Meth.pdf
Leakage: all sources addressed or accounted for			N	19/CP.9	\$4.3/11	Text box 10
Ex-post leakage as identified in simplified baseline methodology			S			Text box 4
Ex-ante calculation of actual net GHG removal			N/S			Text box 6
MONITORING METHODOLOGY AND MONITORING PLAN				19/CP.9 H	\$6 /	7 / 8
Check for relevant guidelines and instructions of EB			N/S			http://cdm.unfccc.int/EB/Meetings
Use existing approved or nearly approved methodologies, if appropriate			N			Text box 5; http://cdm.unfccc.int/methodologies/ARmethodologies
Use existing approved or nearly approved simplified methodologies, if appropriate			S			Text box 4; http://cdm.unfccc.int/methodologies/ARmethodologies ; http://cdm.unfccc.int/Panels/ar/ARWG06_repan2_AR_SSC_Meth.pdf
Submit for approval if new (simplified) methodology			N/S		\$5.6	Text box 5; CDM-AR-NM form at: http://cdm.unfccc.int/EB/Meetings/022/eb22_repan14.pdf ; See also: http://cdm.unfccc.int/EB/Meetings/021/eb21repan18.pdf ; http://cdm.unfccc.int/methodologies/Reference/Documents

Requirement / activity	PIN	Scale	Reference	Sourcebook Section	Comment
All greenhouse gases included		N		\$9	Text box 8
Only carbon stock changes required		S			Text box 4
All ecosystem compartments in soil and biomass included		N		\$6.4 / 9	Text box 8
Only above and belowground biomass included		S			Text box 4
Monitoring methodology in agreement with baseline methodology		N/S			Text box 6
Leakage		N/S		\$11	Text boxes 4 and 10
Quality assurance		N/S		\$10	Text box 6
PROJECT DESIGN DOCUMENT					
Check for relevant guidelines and instructions of EB		N/S			http://cdm.unfccc.int/EB/Meetings
Use the CDM-AR-PDD form		N/S			http://cdm.unfccc.int/methodologies/Reference/Documents
Crediting period and operational lifetime	*	N/S		\$4.4 / 5.5	Text box 11
Address participation requirements		N/S			See 'Participation requirements'
Address project design		N/S			
Address additionality		N/S			See 'Baseline methodology – Additionality'
Address baseline study		N/S			See 'Baseline methodology'
Address leakage		N/S			See 'Baseline methodology'
Address monitoring methodology and monitoring plan		N/S			See 'Monitoring methodology'
Environmental Impact Assessment		N/S	17/CP.7 G.37		Must be included in the PDD
Stakeholders' comments		N/S	17/CP.7 A1; G37; I62		Must be included in the PDD

Requirement / activity	PIN	Scale	Reference	Sourcebook Section	Comment
LEGAL ISSUES - OWNERSHIP					
Legal issues guidebook		N/S			www.uneptie.org ; www.cd4cdm.org
Land titles or customary rights to the land	*	N/S			Text box 12
Entitlement to GHG reductions / CERs ('seller')	*	N/S			Text box 12
CERs versus VERs		N/S			Text box 12
Payment of transaction costs		N/S			Text box 12
Types of risks to be addressed		N/S			Text box 12
Liabilities and indemnities		N/S			Text box 12

1. Steps towards CDM registration

An A/R CDM project activity must be registered to be issued CERs. For registration it has to go through the following steps:

- The A/R CDM project activity has to be described using the CDM-AR-PDD form.
- If the A/R CDM project activity does not employ approved baseline and monitoring methodologies, the new methodologies must be submitted first for approval (see Text box 5).
- The PDD has to be submitted to a DOE.
- The DOE checks the application and the PDD against the CDM requirements.
- The A/R CDM project activity proponent must have approval from the host Party's DNA. The DNA will state that the host Party has ratified the Kyoto Protocol, assess whether project participation is voluntary and whether the A/R CDM project activity meets the sustainable development criteria (see Text box 3). The approval is required prior to registration, not necessarily prior to the DOE's validation procedure.
- If the DOE determines the proposed A/R CDM project activity to be valid, it submits a request to the EB for registration of the A/R CDM project activity. This request takes the form of a validation report. In addition, the PDD and the host Party approval are handed in. The EB charges a registration fee.
- The COP and the EB have set deadlines for various steps in the review and registration procedures. Procedures and deadlines may change. Therefore check the EB web site regularly. (<http://cdm.unfccc.int/EB/Meetings>)

(17/CP.7 Annex G; 18/CP.9 Annex II; 19/CP.9 Annex G)

2. Definition of 'forest', eligible A/R CDM project activities, '31 December 1989 rule'

The decision of what constitutes a forest has implications for what lands are available for afforestation and reforestation activities. DNAs have been given the role of deciding for their country where to lay the thresholds from the available range:

- Minimum tree crown cover value between 10 and 30 percent
 - Minimum land area value between 0.05 and 1 hectare
 - Minimum tree height value between 2 and 5 metres
- (11/CP.7 Annex A.1a; 19/CP.9 Annex F)

There are two categories of eligible A/R CDM project activities, viz. 'afforestation' and 'reforestation'. Forest management or avoidance of deforestation are not eligible A/R CDM project activities for the first commitment period. (17/CP.7 Art. 7a; 11/CP.7 Annex D.12)

Afforestation is the direct human-induced conversion of land, that has not been forested for a period of at least 50 years, to forested land through planting, seeding and/or the human-induced promotion of natural seed sources. (11/CP.7 Annex A.1b)

Reforestation is the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forest land. For the first commitment period, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December 1989. (11/CP.7 Annex A.1c)

In practice, no distinction is made under the CDM between afforestation and reforestation. Therefore, the criterion that all A/R CDM project activities must meet, is no forest to be present within the project boundaries between 31 December 1989 and the start of the A/R CDM project activity. The CDM EB provides a tool to define the eligibility of land. (http://cdm.unfccc.int/EB/Meetings/022/eb22_repan16.pdf)

In the Marrakech Accords it is stated that A/R CDM project activities must contribute to the conservation of biodiversity and sustainable use of natural resources. (11/CP.7)

For the first commitment period, the total of additions to a Party's assigned amount resulting from A/R CDM project activities may not exceed 1% of the base year emissions (1989) of that Party, times 5. (17/CP.7 Art. 7b; 11/CP.7 Annex D.14)

3. Sustainable development criteria

One requirement of a CDM project activity is that it must contribute to the sustainable development of the host party. The DNAs have been given the role to define criteria for sustainable development. These criteria are likely to include the following:

- Environmental impact
- Social impact
- Economic impact
- Technology transfer

Meeting these criteria will be part of the approval procedure by the DNA.
(17/CP.7 Annex G.40)

4. Small-scale A/R CDM project activities

Small-scale A/R CDM project activities may not generate more than a maximum of 8,000 t CO₂-e/y on average over five years. Example: assuming an average net carbon sequestration of 10 tC/ha, this implies a maximum area of 218 ha of forest. (19/CP.9 Annex A.1i)

Small-scale A/R CDM project activities may not be the result of a de-bundled larger scale activity. The three following criteria must all apply for projects to be deemed de-bundled: the same project participants, registered within the previous two years and boundaries within 1km. For example, a set of small-scale A/R CDM project activities from the same proponent and registered at the same time should fulfil the criterion to be at least 1km apart. (14/CP.10 Annex B.4c and App C)

Indicative simplified methodologies are provided (14/CP.10 Appendix B) and, so far, one detailed baseline and one related monitoring methodology for small-scale A/R CDM project activities have been proposed by the AR WG, for grassland and cropland to forested land. In this methodology, only carbon stock changes in above- and belowground biomass need to be quantified and leakage can be estimated ex-post. (http://cdm.unfccc.int/Panels/ar/ARWG06_repan2_AR_SSC_Meth.pdf)

Modalities for A/R CDM project activities partly apply to small-scale A/R CDM project activities (19/CP.9 I-11). For the latter, simplified modalities have been defined. (14/CP.10)

5. Steps towards new baseline and monitoring methodologies

Existing approved methodologies or parts of these methodologies should be used as much as possible, if applicable, to the proposed new A/R CDM project activity, to avoid or reduce the bureaucracy of getting a new methodology approved by the CDM EB.

Submissions of different methodologies for similar A/R CDM project activities in the same country or region should be avoided.

The PDD asks project developers to use an approved A/R methodology. Where no approved methodology exists which could be applied to the A/R CDM project activity in question, a new methodology has to be formulated and submitted through a DOE. Once they are approved, other project developers can use them as well. A baseline methodology includes a number of issues, not just the baseline (the name is thus somewhat misleading) including:

- Land eligibility,
- Baseline scenario,
- Project scenario,
- Additionality,
- Leakage and
- Estimation of greenhouse gas benefits generated by the A/R CDM project activity.

A monitoring methodology describes how the GHG effects of the A/R CDM project activity are to be measured / monitored.

For a new methodology to be approved, the following steps need to be taken:

- The project proponent shall propose a new A/R methodology, through a DOE or an AE. The following completed documents are needed: a CDM-AR-NM (for both baseline and monitoring methodologies – previously there were two separate documents, NMB and NMM; http://cdm.unfccc.int/EB/Meetings/022/eb22_repan14.pdf) and a draft CDM-AR-PDD (with completed sections A-D). A methodology can be submitted only in combination with a concrete A/R CDM project activity that applies the methodology.
- The DOE/AE and the CDM AR WG go through an interactive reviewing process with short response times for the project proponent.
- The EB attributes a final rating to the methodology (A: approval, B: resubmit – to be resubmitted with required improvements within 5 months or C: non-approval).

(19/CP.9 Annex H; <http://cdm.unfccc.int/EB/Meetings/021/eb21repan18.pdf>)

Modalities for monitoring of CDM project activities are provided in the Marrakech Accords and COP 9 decisions. (17/CP.7 Annex H; 19/CP.9 Annex H)

The COP and the CDM EB have set deadlines for various steps in the review and registration procedures. Procedures and deadlines may change. Therefore check the EB web site regularly. (<http://cdm.unfccc.int/EB/Meetings>)

6. Technical standards for documentation

At its 21st meeting in September 2005, the CDM EB published a second version of guidelines on formulating the A/R PDD, NMB and NMM (Clean Development Mechanism Guidelines for Completing the Project Design Document for A/R [CDM-AR-PDD]) (<http://cdm.unfccc.int/EB/Meetings/021/eb21repan19>).

pdf), the proposed new methodology for A/R: Baseline (CDM-AR-NMB) and the proposed new methodology for A/R: Monitoring (CDM-AR-NMM)). The guidelines are very specific and give relatively clear instructions. It is strongly recommended to go through this document when writing an A/R PDD and NM. The CDM A/R WG expects high standards for CDM A/R documentation. This pertains to completeness, the proper use of definitions and accuracy. The above-mentioned guidelines include a glossary that provide guidance in using the right language for the documentation. Furthermore, it is recommended to check and take into account information and clarifications published by the CDM EB.

Some specific recommendations include:

- Use proper definitions for additionality, leakage and project boundary.
- Ex-ante calculations of net GHG removals must be included in the baseline methodology. It is not sufficient to define the methodology for quantifying these ex-post.
- The selection of the most plausible baseline scenario must be separated from the additionality assessment.
- Make sure that the estimation of actual net GHG removals is performed in a complete, transparent, conservative and verifiable manner. For definitions of these terms see the above-mentioned glossary.
- Accuracy must be adequate. Quantifications (ex-ante as well as ex-post) must be accompanied by error assessments and outcomes must be conservative. Formulae etc. must be well defined, contain no errors and be adequately referenced. Take note of the relevant specific guidelines from the CDM EB.
- Quality assurance must be taken seriously. For verifiable and certifiable measurements of changes in carbon stocks provisions for quality assurance and quality control to be implemented are required, providing confidence to all stakeholders that the reported carbon credits are reliable and meet minimum measurement standards.
- Methodologies must be described in a logical, step-wise 'cook book' approach with unambiguous use of terminology.
- Baseline and monitoring methodologies must be mutually consistent, as they must also be proposed and approved together.

7. Selection of baseline approach

Three approaches to creating a baseline are available for selection. Project developers have to select the most appropriate approach and justify their selection:

- a) Existing or historical, as applicable, changes in carbon stocks in the carbon pools within the project boundary;
- b) Changes in carbon stocks in the carbon pools within the project boundary from a land use that represents an economically attractive course of action, taking into account barriers to investment;
- c) Changes in carbon stocks in the pools within the project boundary from the most likely land use at the time the A/R CDM project activity starts.

(19/CP.9 Annex G.22)

The baseline scenario can either be estimated and validated upfront and then "frozen" for the first phase of the crediting period (30 years, or the first 20 years of up to 60 years) (19/CP.9 Annex G.23), or it is also possible to monitor the baseline during the A/R CDM project activity.

It is advisable to define more than one alternative baseline scenarios. The project scenario should at this stage be regarded as one of these scenarios. The baseline scenario is the most plausible of alternatives identified and its choice must be substantiated.

A baseline must be established in a transparent and conservative manner. (19/CP.9 Annex G.20)

8. GHG gases and ecosystem compartments to be considered

Two other gases besides carbon dioxide (CO₂) that are related to land-use change activities are methane and nitrous oxide. Although these gases are produced in smaller quantities than CO₂, their effect for a given mass on global warming is greater (21 and 296 times that of CO₂, respectively).

Methane and nitrous oxide are produced mainly as the result of anthropogenic activities, for example the use of machinery, fires, the draining of wetland regions, and the fertilisation of land.

Methods for estimating these non-CO₂ GHG emissions can be found in the IPCC *Good Practice Guidance on Land Use, Land-Use Change and Forestry* (2003).

There are six carbon pools applicable to A/R CDM project activities: aboveground tree biomass, aboveground non-tree biomass, belowground biomass, litter, dead wood and soil organic matter. (19/CP.9 Annex A.1) However, not all six pools will be significantly impacted in a given project. (11/CP.7 Annex E.21) Project participants may choose not to account for one or more carbon pools, subject to the provision of transparent and verifiable information that the choice will not increase the expected net anthropogenic greenhouse gas removals by sinks. Therefore pools can be excluded as long as it can reasonably be shown that the pool will not decrease as part of the project activity or will not increase as part of the baseline. Definitions of pools can be found in the IPCC *Good Practice Guidance on Land Use, Land-Use Change and Forestry* (2003) (<http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>).

9. Determination of additionality

Additionality is not the mere difference between baseline and project scenarios. The additionality assessment is to show that the project activity would not have occurred in the absence of the A/R CDM project activity. (17/CP.7 Annex F.34; 19/CP.9 Annex G.10d) Nevertheless, there must be consistency between the determination of the baseline scenario (Text box 7) and the determination of additionality.

The EB developed a step-wise tool to test the additionality of prospective project activities (Tool for the demonstration and assessment of additionality in A/R CDM project activities – <http://cdm.unfccc.int/EB/Meetings/021/eb21repan16.pdf>). This tool covers a wide range of activities but can be adapted if need arises. For small-scale A/R CDM project activities, the AR WG has developed a specific method for the assessment of additionality. (http://cdm.unfccc.int/Panels/ar/ARWG06_repan2_AR_SSC_Meth.pdf; Attachment B)

Further considerations include:

- ODA eligibility: potential public funding for the A/R CDM project activity from Parties in Annex I shall not be a diversion of official development assistance. (17/CP.7)
- In case of the existence of a background reforestation or tree planting programme, the project must substantiate that there will be no interference with this programme to demonstrate additionality.

10. Leakage

Leakage is the increase in GHG emissions occurring outside the project boundary of an A/R CDM project activity which is measurable and attributable to the activity. (19/CP. Annex A.1e)

For example, leakage can be due to displaced agricultural activities and cattle raising (CO₂ and non-CO₂), or due to displaced farmers cutting forest to replace land that is reforested as part of the project.

It is recommended to address leakage in the project design (19/CP.9 Annex G.24) or otherwise account for it by subtracting it from the project performance. Only negative leakage (increased GHG emissions) must be included. Positive leakage (reduced GHG emissions) – although a beneficial result of the activity – may not be accounted for.

11. Crediting period and operational lifetime

A/R CDM project activities generate expiring CER units in two forms: tCER (temporary CERs) and ICER (long-term CERs). These types of CER have been instituted to address the issue of non-permanence. tCERs expire at the end of the commitment period following the one during which they were issued, that is, they last for five years if subsequent commitment periods are five years. (19/CP.9 Annex A.1g) ICERs last for the entire length of the crediting period. (19/CP.9 Annex A.1h) For both types of CERs, there is a choice between a single crediting period of a maximum of 30 years or a period of 20 years with the possibility of renewal twice (totalling 60 years). These two choices must be made in the PDD. (19/CP.9 Annex A.1gh/G.23/K)

Normally, the crediting period can only start after the date of registration. However, A/R CDM project activities that have already started (with a start date after 1 January 2000) can register with the EB after 31 December 2005 and begin the crediting period as early as 1 January 2000. Decisions 17/CP.7 12 and 13 do not apply to A/R CDM project activities, as stated by the EB at its 21st meeting. (<http://cdm.unfccc.int/EB/Meetings/021/eb21rep.pdf>, paras 63 and 64) Therefore, A/R CDM project activities can accumulate CERs from 1 January 2000 on which can be used for compliance purposes in the commitment period 2008-2012.

The operational lifetime must be at least the same as the crediting period. The date on which the project start implementing, resulting in the actual net GHG removal is the same as the start of the crediting period.

12. Legal issues

A project developer must deal with a variety of legal issues during the project development cycle. The issues have been dealt with in some detail in the UNEP Legal Issues Guidebook to the Clean Development Mechanism. For the purpose of drafting a PIN, it is sufficient to assess land titles or customary rights to land, as

this has a bearing on who will have ownership of the products of the CDM A/R project activity, depending on local legislation.

In particular the following issues must not be overlooked in the PDD writing stage:

- Entitlement to GHG reductions/CERs: Check local legislation to assess if the host country government has pre-existing rights on CERs or if land owners also own the CERs generated on their land. Establish who exactly is the seller of the CERs.
- CERs versus VERs: Establish the nature of the rights being sold. CERs are not generated if the project fails, but in that case VERs may still be a second option.
- Payment of transaction costs: It must be clear who will pay for the cost of creating CERs, including hiring a DOE, registration and monitoring and verification. If these costs are not part of the CER's price, they must be allocated to either the buyer or the seller.
- Types of risks to be addressed: Policy risk (political and regulatory uncertainties in developing countries) and A/R CDM project activity risk (occurring in any kind of project) can be dealt with in contracts and are usually reflected in the purchasing price of the CERs. For example, European companies buy emission reductions from the European Emission Trading system (low risk) at a higher price than CERs from CDM projects (higher risk). Kyoto Protocol risks are specific to this legal framework and include, amongst others, unexpected changes in international agreements, opposition of NGOs, CER market risks, failing compliance with Kyoto Protocol and related rules, etc. These risks must be contractually assigned.
- Liabilities and indemnities: Ensure that no liabilities exist that are beyond the control of the project developer.

(www.uneptie.org/energy/publications/pdfs/CDMLegalIssuesguide-book.pdf or www.cd4cdm.org/Publications/CDM%20Legal%20Issues%20Guidebook.pdf)

